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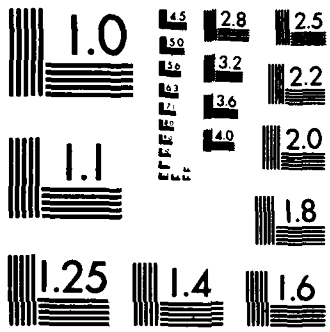

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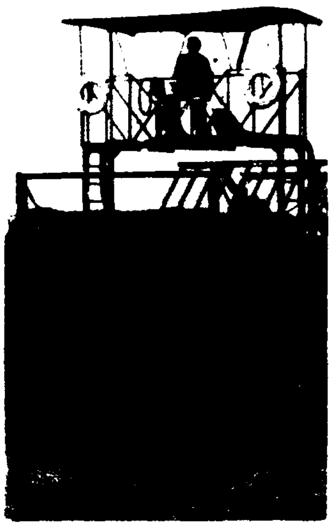

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AQUATIC PLANT CONTROL RESEARCH PROGRAM

MISCELLANEOUS PAPER A-83-8

SIMULATED MECHANICAL CONTROL OF AQUATIC PLANTS IN BUFFALO LAKE, WISCONSIN

by

Bruce M. Sabol

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

U.S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

October 1983

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To determine the operational time required to mechanically control nuisance-level growth of aquatic plants in Buffalo Lake, Wisconsin, a computer model (HARVEST) was used which simulates all important steps in a mechanical control operation. Model inputs include plant density, distance to nearest disposal site, and mechanical and performance specifications for the harvesting system used. Plant densities were determined at two different times

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20. ABSTRACT (Continued).

during the growing season by conducting a quantitative field sampling program coupled with aerial photography. A treatment area was selected which consisted of boat lanes covering approximately 20 percent of the area in the eastern two thirds of the lake. The Aquamarine H8-650 and H-400 harvester were selected for simulation. Mechanical control operations were simulated in the treatment area for the two summer periods using each harvester working alone and with a single Aquamarine T-650 transport unit.

Surface-topped growth of aquatic plants within the harvestable portion of Buffalo Lake during early and late summer periods covered 35 and 50 percent, respectively, of that area. Harvestable density within the treatment area during early and late summer periods averaged 5.9 and 7.9 tons/acre, respectively. Coontail (*Ceratophyllum demersum*) was the dominant plant species encountered.

Predicted control operation times ranged from 215 to 440 hr for the early summer period and 297 to 627 hr for the late summer period. Predicted production rates were greatest for the H8-650 harvester working with a transport unit. Recommendations are made of means to determine the most cost-effective combination of equipment.

PREFACE

This report describes the findings of a computer simulation study performed to determine the operational effort required to mechanically control aquatic plants in Buffalo Lake, Wisconsin. The work was performed by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) during the period June 1982 - August 1982. The study was sponsored by the U. S. Army Engineer District, St. Paul. Messrs. Wayne Koerner and Dave Haumersen, St. Paul District, were the Technical Monitors for the study.

Messrs. Bruce M. Sabol and Flynn A. Clark, both of the Battlefield Environment Group (BEG), Environmental Laboratory (EL), WES, were responsible for the collection and interpretation of field data. Mr. Thomas D. Hutto of BEG was responsible for the simulation of mechanical control operations using the WES HARVEST computer model. This report was prepared by Mr. Sabol. Mr. Dale Brege of the Wisconsin Department of the Natural Resources and Mrs. Mary Albert of the Buffalo Lake Property Owners Association provided assistance during the planning phase of the study.

The work was conducted under the direct supervision of Mr. H. Wade West of BEG, and under the general supervision of Dr. Daniel H. Cress, Chief, BEG; Mr. Bob O. Benn, Chief, Environmental Systems Division; and Dr. John Harrison, Chief, EL. Mr. J. Lewis Decell was Manager of the Aquatic Plant Control Research Program.

COL Tilford C. Creel, CE, was the Commander and Director of WES during the conduct of this study. Mr. F. R. Brown was the Technical Director of WES. COL Edward G. Rapp, CE, was the St. Paul District Engineer.

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CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
miles (U. S. statute)	1.609347	kilometres
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (mass) per acre	0.22	kilograms per square metre
tons (2000 lb mass)	907.1847	kilograms

SIMULATED MECHANICAL CONTROL OF AQUATIC PLANTS IN BUFFALO LAKE, WISCONSIN

PART I: INTRODUCTION

Background

1. Buffalo Lake is a large (2500 acres*), shallow (mean depth = 4 ft) impoundment located in Marquette County, Wisconsin (Figure 1). Since the removal of rough fish in 1970, various species of submerged aquatic plants have reached nuisance-level densities resulting in decreased recreational usage of the lake. At the request of the Wisconsin Department of Natural Resources, the U. S. Army Engineer District, St. Paul, conducted a reconnaissance study to determine the extent of the problem and to establish the need for a cost-sharing aquatic plant control program under the provisions of the Rivers and Harbors Act of 1965 (Public Law (PL) 89-298). The St. Paul District study concluded that the problem at Buffalo Lake was severe and that a control program was needed. Both mechanical and chemical control alternatives were considered, but mechanical methods were selected because it was felt that chemical methods would be ineffective given the current pattern within the impoundment and the diversity of the aquatic plant community (U. S. Army Engineer District, St. Paul 1980). Preliminary estimates of benefits and costs indicated that a mechanical control program would be economically justified. The St. Paul District subsequently requested the assistance of the U. S. Army Engineer Waterways Experiment Station (WES) to analyze selected mechanical control options using the HARVEST computer model developed at WES.

2. Mechanical treatment of the entire lake would not be practical; therefore, it was necessary to delineate limited areas within the lake within which it would be desirable to remove nuisance level plant growth. The delineation of the treatment areas involved:

a. Delineation of areas within the lake where plants should be maintained below nuisance levels.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

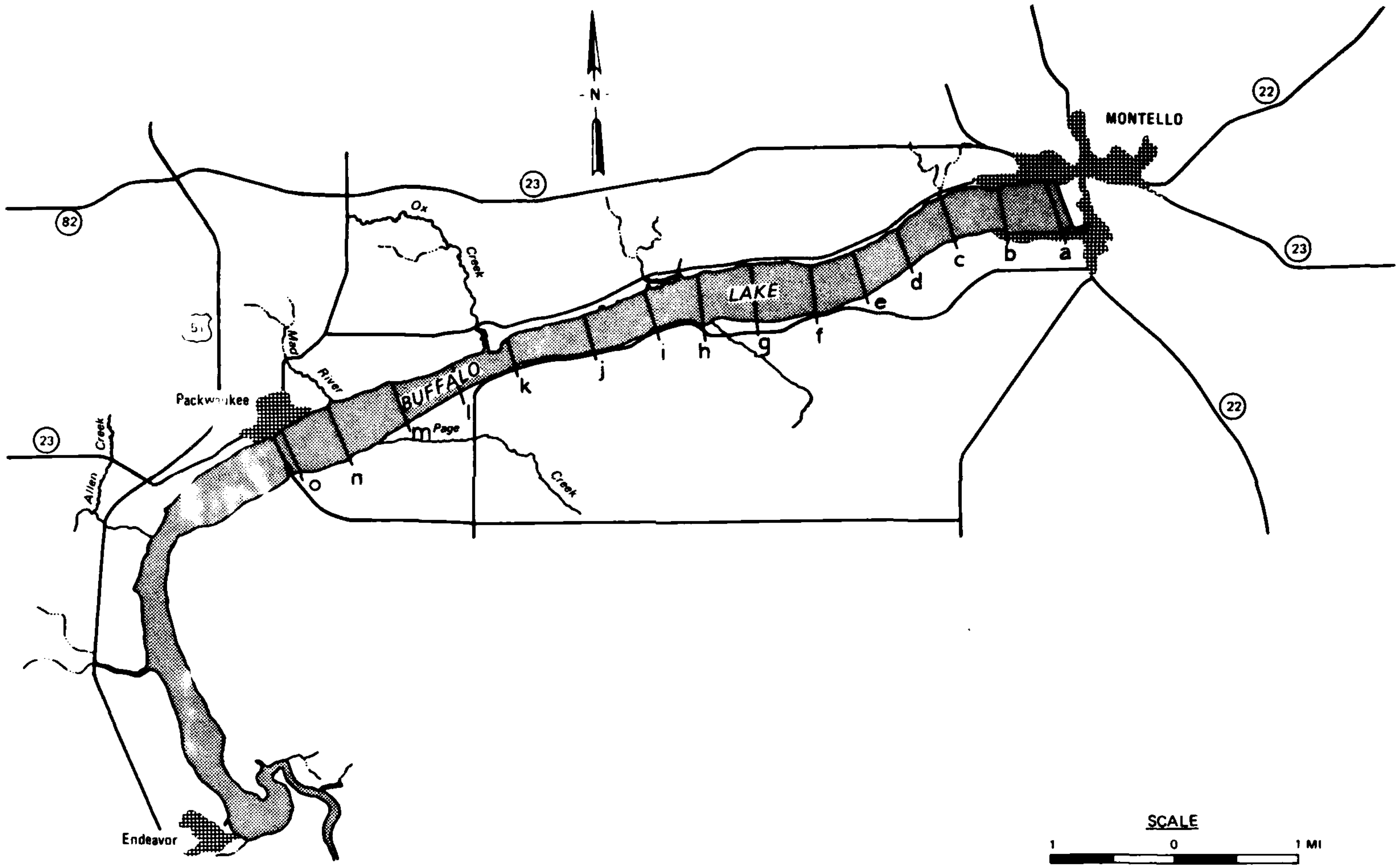

Figure 1. Buffalo Lake study area. Study transects (a-o) are also shown

b. Mapping the plant density distribution within the lake at two different times during the growing season.

c. Determining, through superpositioning the areas that will be maintained below the nuisance level of plant density on the plant density maps, the areas that have the greatest need for mechanical removal of the plants. The plant density maps within the areas selected for mechanical treatment and the locations of prospective shore disposal sites were used as inputs to the HARVEST model. The model was then run to predict the time to effect mechanical control at two different times during the growing season using selected combinations of equipment.

Objectives and Scope

3. The objectives of this study were:

a. Qualitatively and quantitatively describe the distribution of aquatic plants within Buffalo Lake at two different times during the growing season.

b. Predict the operational time required (using the WES HARVEST simulation model) to conduct mechanical control operations for:

(1) Selected harvestable areas within the lake totaling approximately 20 percent of the lake area.

(2) Two different harvesting systems each with two different mixes of equipment.

(3) Plant density conditions during an early and a late summer period.

4. Part II of this report presents methods used in the quantification of plant infestations in the lake, the selection of areas where plants would be maintained below nuisance level densities, and the determination of the location of prospective shore disposal sites. In addition, the selection of the harvesting systems and the determination of the equipment performance specifications are presented. Finally, the HARVEST model and its use are discussed. An analysis of the results of the study is presented in Part III. Part IV contains conclusions and recommendations resulting from the study.

Rationale

5. The rationale for conducting a study of this nature is based on the fact that the operational manager needs to know the effects of aquatic plant conditions (such as biomass and height) on harvesting system performance and needs reliable predictions of harvesting equipment performance in the

plant-infested water body so that a cost-effective mechanical control operation can be planned and implemented. In the past, predictions of expected mechanical control system performance have frequently been unreliable because:

a. They were "rule-of-thumb" estimates which did not take into account important interactions between plant density, disposal site locations, and mechanicl system performance.

b. They were based on general assumptions which may not be applicable to the water body for which operations are proposed. Such assumptions may include:

   (1) Only large harvesters are cost-effective.

   (2) Harvesters should always operate with separate transport units.

It seems apparent that predictions, which provide quantitative da concerning aquatic plant harvesting times and rates, would be a signific improvement to aquatic plant control operations planning. The WES HARVE del provides such data.

PART II: METHODS

6. Preliminary information on Buffalo Lake and its problems was obtained from local individuals familiar with the lake. This information, in conjunction with available maps and aerial photographs, was used to develop an aquatic plant sampling plan. During early summer (30 June through 8 July 1982) and late summer (19-23 August 1982) periods, quantitative plant samples were collected along evenly spaced transects, perpendicular to shore, between Montello and Packwaukee on Buffalo Lake. Aerial photography missions were concurrently performed. Quantitative plant density distribution for the lake was estimated using the aerial photographs and the field sampling with the WES aquatic plant sampler. A treatment area was selected, based on lake usage considerations, where plants would be maintained below nuisance level densities. Plant density distribution estimates within this area and the locations of prospective shore disposal sites were used as inputs to the HARVEST model which was run to simulate mechanical control using several types and combinations of equipment. A flow diagram of the overall methodology is illustrated in Figure 2 and is discussed in the following paragraphs.

Aquatic Plant Distribution

Field procedures

7. Plant identification. Prior to initiating quantitative sampling, a plant reconnaissance survey of the lake was conducted. Whole plant samples of as many different species as could be found were collected. Fresh plant samples were identified using the taxonomic keys of Fassett (1974), Edmondson (1959), Prescott (1969), and Correll and Correll (1972). Whole specimens of each taxon encountered were pressed for taxonomic confirmation by botanists at WES. Table 1 lists the species encountered, in descending order of abundance.

8. Sampling. A modified stratified random sampling design was used to estimate plant densities. Fifteen permanent transects perpendicular to the shoreline were established at an interval of approximately 0.75 km between Montello and Packwaukee (shown in Figure 1). Visual examination of the plant growth along each transect was made prior to sample collection; each transect was then visually divided into patches of the following description:

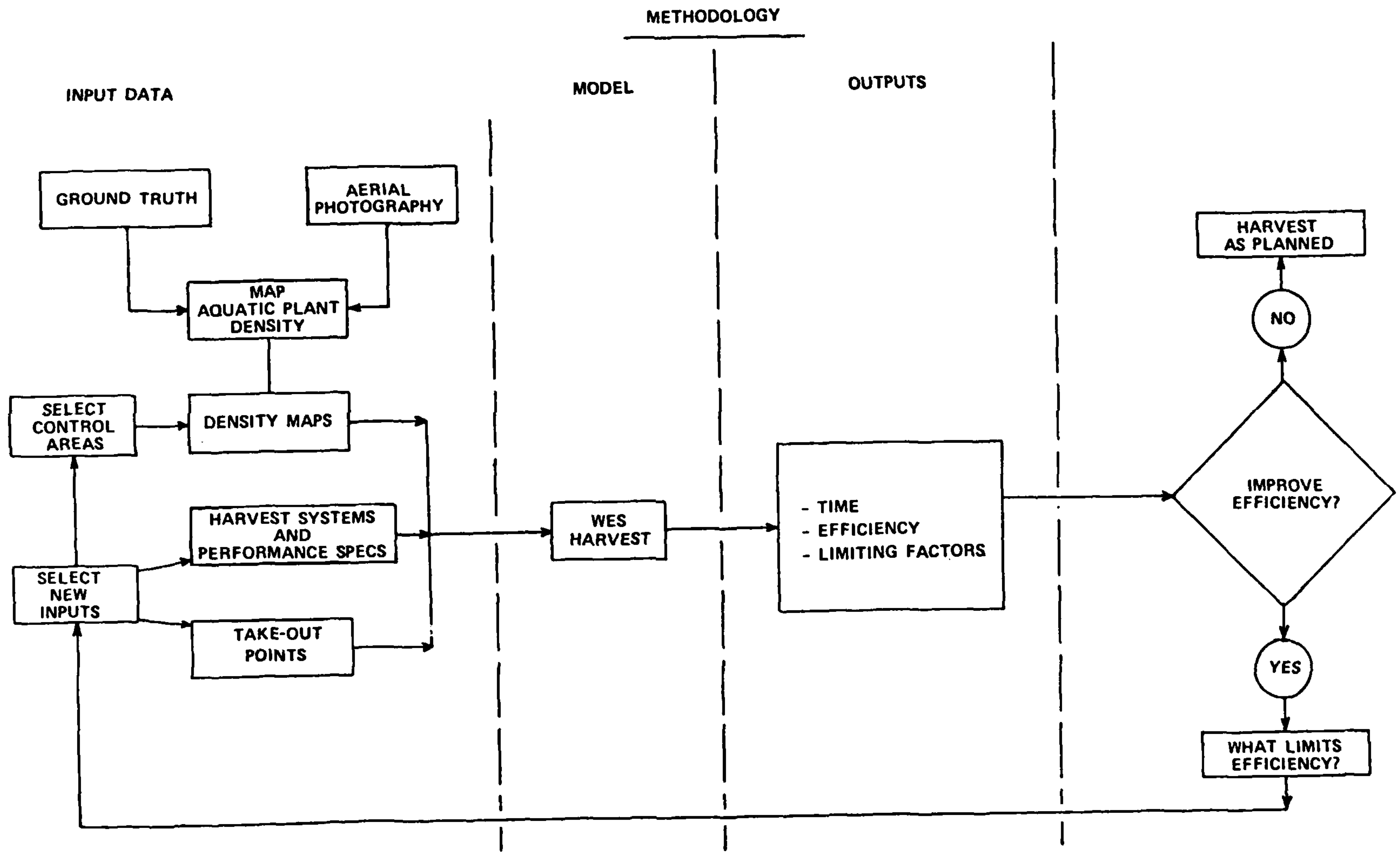

Figure 2. Overview of HARVEST methodology

a. Surface-topped plant growth, i.e., submerged plants growing to the surface.

b. Submerged plant growth visible beneath the surface.

c. No growth visible.

The relative distribution of these patches is shown in Figure 3.

9. Sampling stations were selected in the center of each visually distinct patch or every 100 m when no differences were apparent or when patch variation was too great to sample each individual patch. The distance of the station from shore and total transect width were measured using an optical range finder; station depth was measured using a sounding line. Three replicate plant samples were then taken at randomly selected locations near the center of the patch.

10. All samples were collected with the WES aquatic plant biomass sampler (Sabol 1983). This device consists of a perforated stainless steel box sampler open on the bottom side (Figure 4). Vertical cutter blades, mounted on the bottom edge of the sampler, actively cut a core of plant material as the sampler is slowly lowered to the sampling depth from a hydraulically equipped pontoon boat. At the desired depth, two venetian-blind-type doors, housed inside the sampler along the vertical walls, are pushed closed by hydraulic pistons. Plants are cut off by the knife edge on the leading edge of one door pressing against the flat surface on the leading edge of the other door. The sampler is then retrieved, and plant material is removed through a side door.

11. All samples were taken at full depth by cutting plants off 5 to 10 cm above the sediment interface. Upon retrieval, the relative order of abundance of plants species contained in the sample was recorded. When handling the plants, care was taken not to remove any detritus or epiphytic growth on the plants, as this material contributes to harvestable weight. Samples were labeled and stored in plastic bags in a cooler. At the end of the sampling day all samples were weighed in a field laboratory. All samples were blotted free of excess water on absorbent paper towels and then weighed to the nearest 0.1 g on an electronic top-loading balance. Percent solids measurements were made on approximately 10 percent of the total number of samples collected. This was performed by placing the sample in a drying oven set at 103°C until a constant weight was obtained (usually 48 hr). Percent solids was then computed by dividing the dry weight by the initial wet weight.

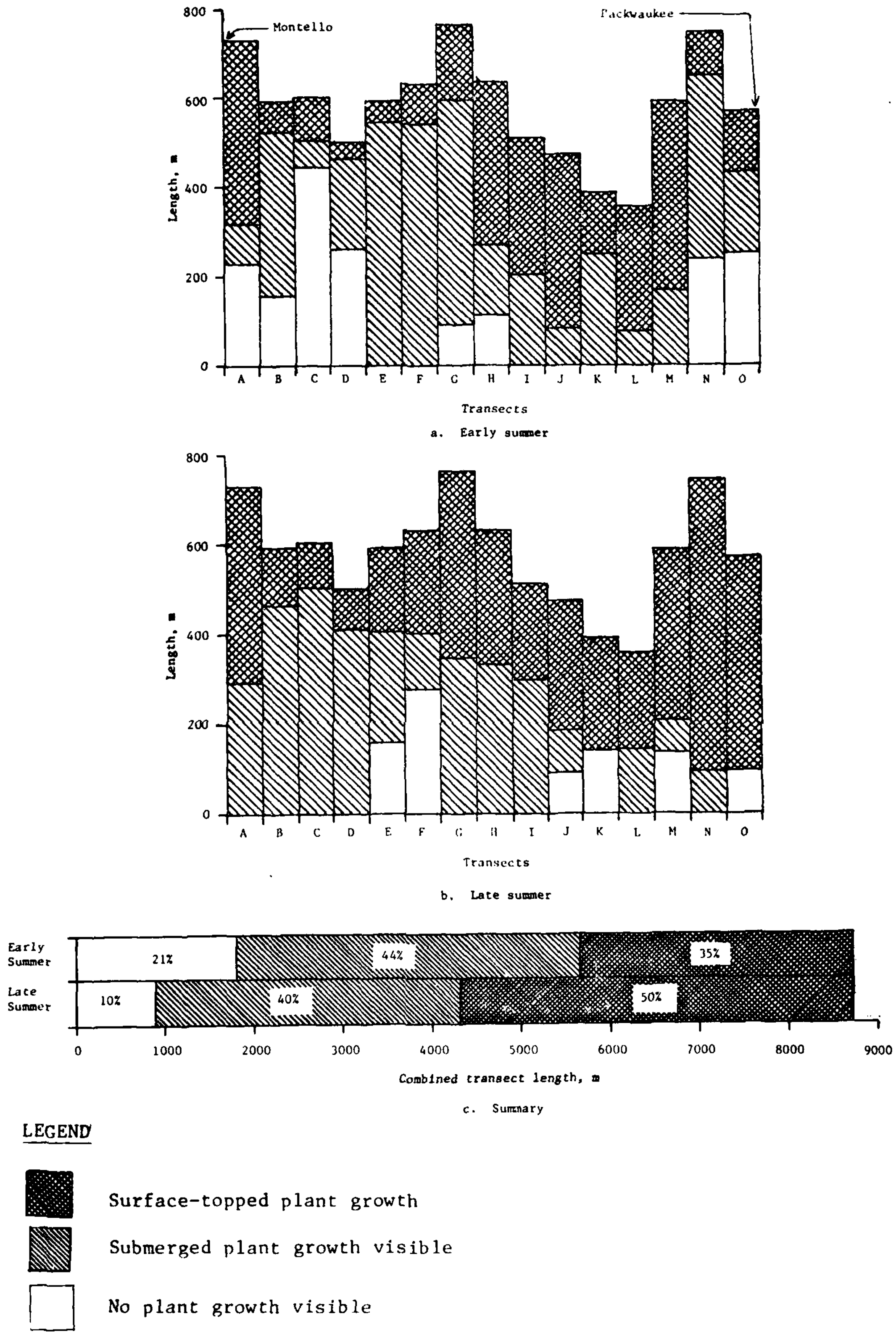

Figure 3. Distribution of aquatic plant patch types

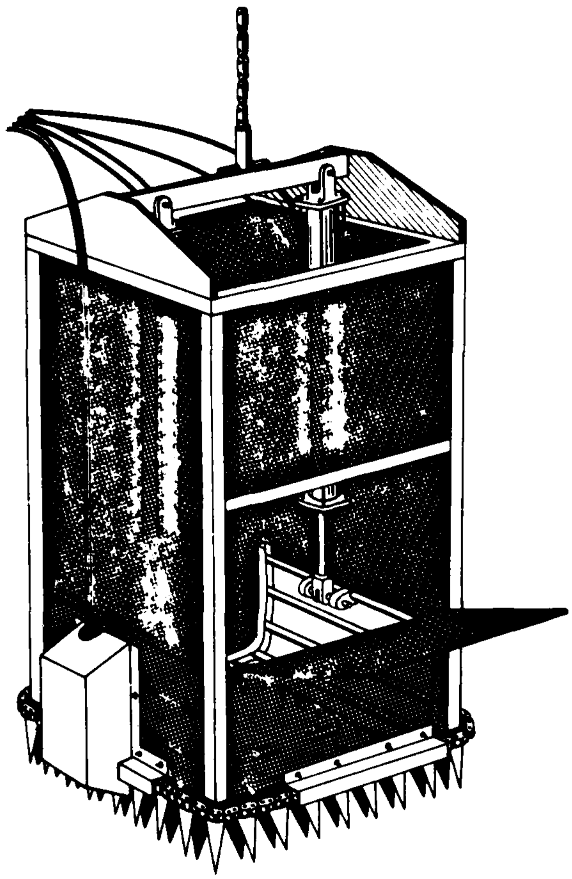

Figure 4. WES aquatic plant biomass sampler

12. All data were placed on standardized data sheets and entered onto computer data files for subsequent data handling and analysis. Individual sample weights were converted to "fresh weight" density (grams per square metre). Mean percent solids was computed by sampling period. Because previous mechanical harvesting research (Hutto and West 1983) has shown an appreciable difference in moisture content between sampled plants (using handling procedures described in paragraph 11) and harvested plants, a moisture content correction is made in fresh weight density in order to estimate harvestable density. Harvestable density was then computed from fresh weight density by mathematically adjusting moisture content to an assumed percent solids of 7 percent (93 percent water) for harvested plant material; units were then converted to tons per acre as required by the HARVEST model. Mean harvestable density at each station was computed from the three replicates taken per station. Overall mean harvestable density for each patch type within the entire area sampled is listed in Table 2.

13. Because of the large number of plant species, plant densities, and bottom depths encountered throughout the lake, it was not possible to develop a generalized lake-wide vertical biomass profile; moreover, time constraints did not permit vertical sampling in each individual combination of dominant species, patch density, and depth. To overcome this problem, dominant plant species were placed into one of three categories according to vertical growth pattern:

a. Submersed plants which tend to have the greatest portion of their biomass towards the top of the plant. These include bottom-rooted plants with submerged leaves scattered along the stem, such as *Myriophyllum*, *Potamogeton*, *Elodea*, *Heteranthera*, and *Najas*.

b. Submersed plants which tend to have the greatest portion of their biomass towards the bottom of the plant. The single species in this category is *Vallisneria americana*.

c. Submersed plants for which vertical biomass distribution is expected to be uniform. This category contains only *Ceratophyllum demersum*, a rootless aquatic plant which drifts within the water column.

14. A single dense patch representing each of the above categories was vertically sampled during both sampling periods. Each patch was divided into three vertical layers (e.g., 0-1 ft, 0-2 ft, and 0-3 ft), and five replicates were taken within each layer. Sampling and weighing was performed as previously described. The results of this characterization are shown in Figure 5.

Aerial photography and interpretation

15. A detailed discussion of the procedures for the use of aerial photography to map aquatic plant distribution, and the limitations of these procedures, may be found in publications by Leonard (1983) and Headquarters, Department of the Army (1979). The methods outlined in the following paragraphs are in accordance with the procedures recommended in these publications.

16. During each sampling period, aerial photo missions were flown over the lake by the Army Aviation Support Facility of the Georgia Air National Guard. True-color (Kodak Aerochrome MS 2448) and color infrared (Kodak Aerochrome infrared 2443) film was used to obtain photography of the entire lake at 4,000, 2,000, and 1,000 ft above ground level. This resulted in imagery with scales of 1:16,000, 1:8,000, and 1:4,000.

17. U. S. Geological Survey 7.5-min maps of the Buffalo Lake area (Montello SE and SW, 1:24,000 scale) were used to construct a base map.

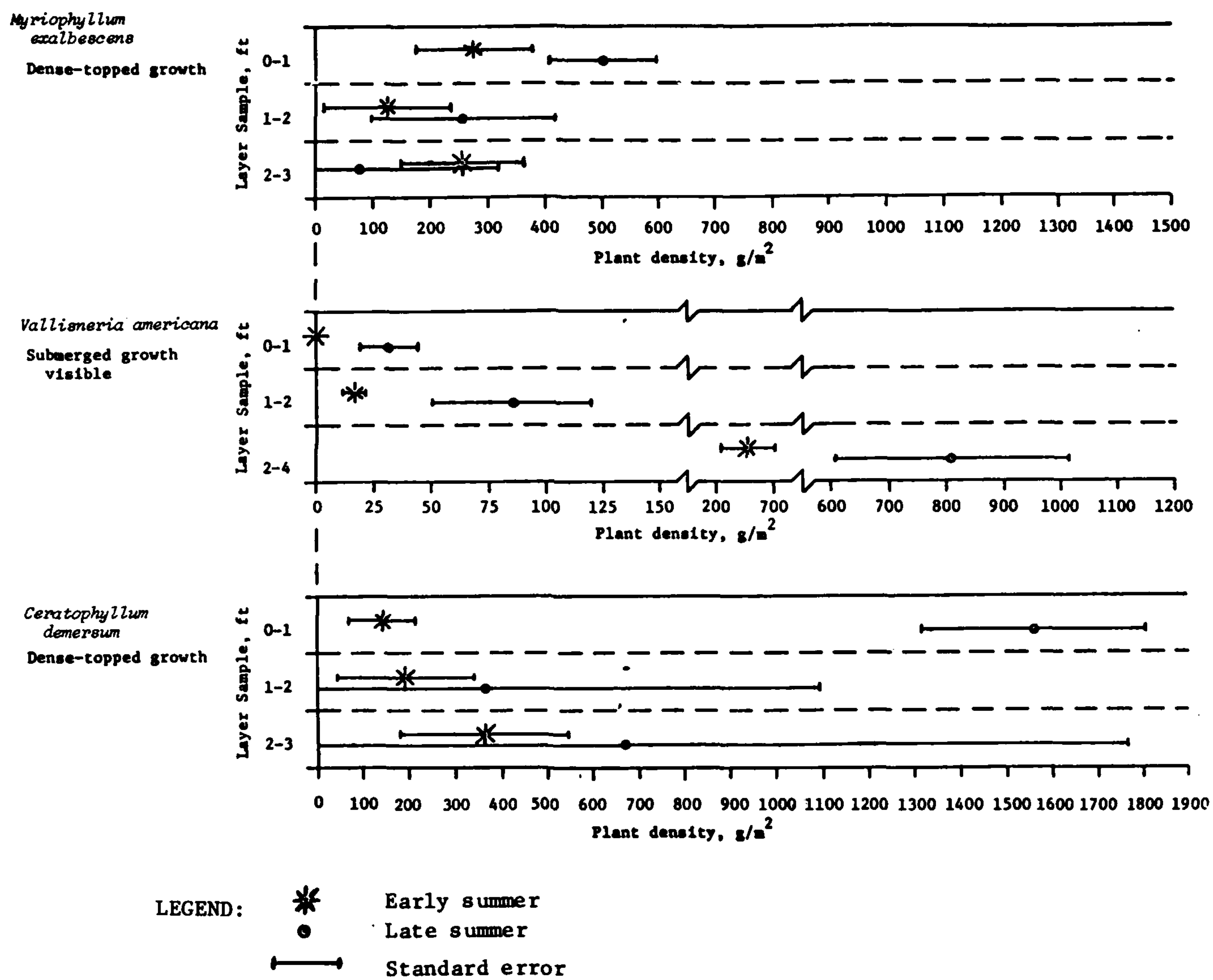

Figure 5. Vertical biomass distribution of dominant aquatic plants

Enlargements of the base map were made at the respective scale of the aerial photography. Patches of surface-topped and submerged plants visible in the photographs were traced directly onto the enlarged base maps. Sampling transects and field sampling stations were located on the base map. The entire area of each patch, delineated from the aerial photographs, was assumed to contain a uniform plant density equal to the mean of the individual samples collected from within that patch. In this way, the plant density for the entire lake between Montello and Packwaukee was estimated for both time periods. Data for the sites selected for analysis by HARVEST are listed in Table 3 for early and late summer periods.

Selection of Treatment Areas, Shore Disposal Sites, and Harvest Sites

Treatment areas

18. For the purpose of this simulation study, it was determined that the portion of the lake where plants would be maintained below nuisance level would be the area between Montello and Packwaukee (Figure 1). This portion was selected because:

- a. It is most heavily developed and used recreationally.
- b. The area west of Packwaukee is relatively less developed and is very shallow with many areas of emergent marshlike vegetation within the lake.
- c. Natural weed-free channels, 4 to 5 ft deep, have been formed by the river directly in front of the only densely developed area west of Packwaukee (Buffalo Shores Estates).

19. A pattern for the area in which plants would be maintained below the nuisance level was selected (without specific regard to location of plant infestations) which consisted of two 150-ft-wide swaths running parallel to the shore on either side of the lake, 300 ft offshore; and 100-ft-wide channels perpendicular to shore every 2000 ft which acted to connect the offshore swaths (Figure 6). This pattern covers 276 acres, approximately 19 percent of the lake area between Montello and Packwaukee.

Shore disposal sites

20. In the present study, a standard mechanical harvesting operation, consisting of removal of the harvested plant material from the water, is simulated. This type of operation requires that shore disposal sites be available. It is further assumed that it may be desirable to transport the

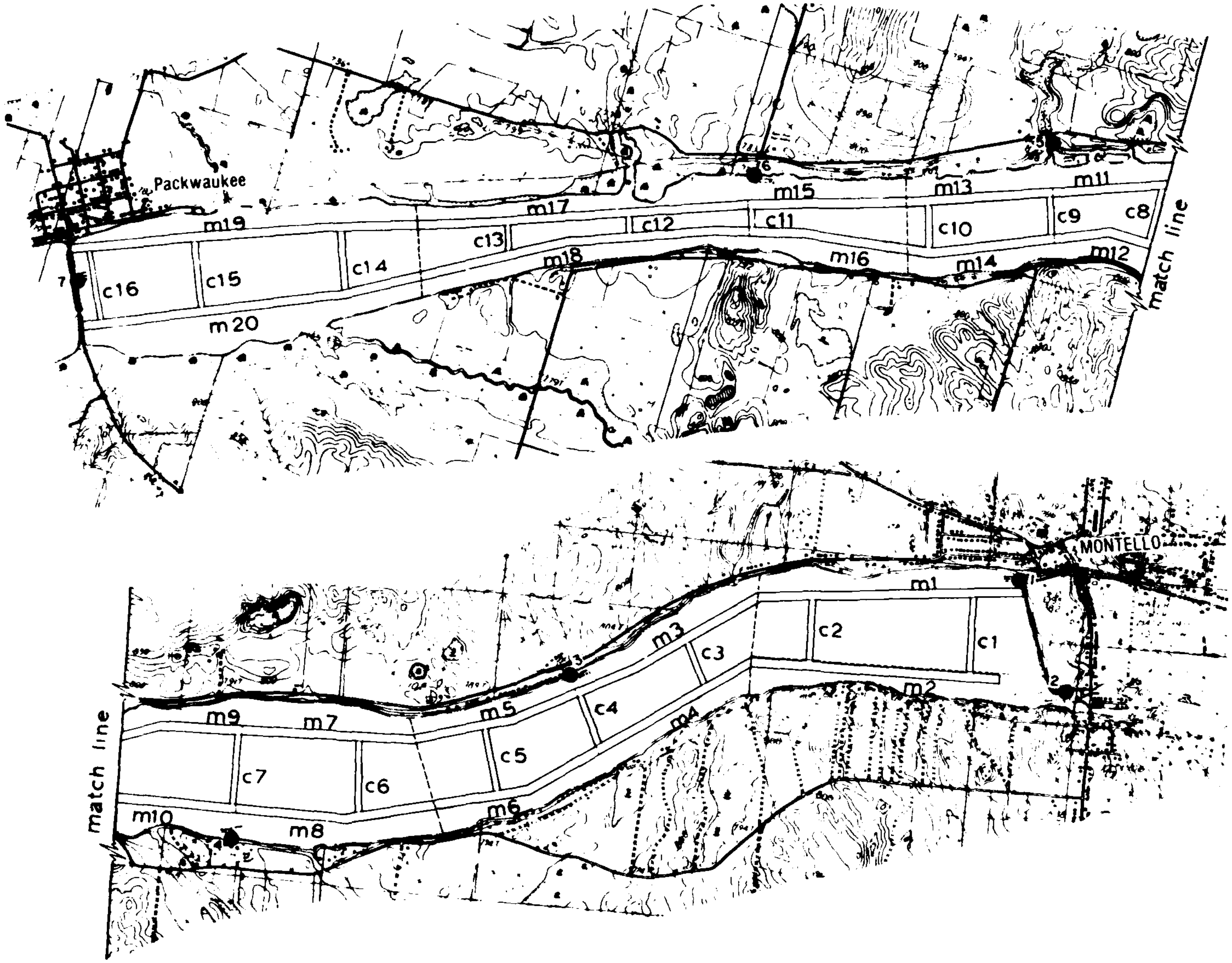

Figure 6. Harvesting treatment area and shore disposal sites (black circles)

harvested plant material to an upland disposal site; this places additional constraints on the selection of shore disposal sites. A candidate shore disposal site must, therefore, be such that a harvester can maneuver directly to the water's edge to unload into a dump truck. Thus, the water side of the site must be deep enough for a harvester and the land side must have a passable road directly to the water's edge. Seven points were identified at which a shore disposal operation would be physically possible. These sites are illustrated in Figure 6 and are listed below by site number:

Site 1. Public access boat ramp in the city of Montello.

Site 2. Old harvest take-out point by the Montello Dam.

Site 3. Boat ramp at Buffalo Lake Lodge.

Site 4. Boat ramp at Shady Rest Resort.

Site 5. Private ramp on north side of lake located 1.0 mile east of the Wisconsin Department of Natural Resources (WDNR) public access.

Site 6. WDNR public access boat ramp.

Site 7. Causeway across lake at Packwaukee.

Harvest sites

21. To determine the dimensions and locations of individual treatment areas, the overall area in which plant infestations would be maintained was first subdivided into regions based on the location of the nearest disposal site. These regions were then further subdivided into individual areas by drawing boundaries within each region so that one corner of each area was a minimum distance from the shore disposal site. These area sites are shown in Figure 6.

22. A map showing areas in which plants would be controlled (Figure 6) was overlaid onto the plant density patch map developed for each sampling period.

23. To select the actual sites to be harvested for each period, the following criteria were applied:

a. Only areas with a harvestable density of 2.0 tons/acre or more would be harvested. Densities less than this do not restrict recreational use of the lake and harvesting these areas would represent inefficient use of the harvesting equipment.

b. A minimum site length of 300 ft was selected so that harvester turning time would be minimized relative to actual working time.

c. When low-density areas (i.e., with less than 2 tons/acre) less than 300 ft long were encountered within a potential harvest

site, the harvester would harvest through rather than turn around to make another pass. When such an area was greater than 300 ft long, the harvester would turn around. This criterion was also used to minimize turning time relative to working time.

24. Using these criteria, individual harvest sites were determined for the two periods. These sites are described by sampling period in Table 3.

25. The boundaries of each individual harvest site, delineated for each period, were drawn on a base map at an enlarged scale. Plant density contour lines (paragraph 17) were drawn within the boundaries. These base maps were then digitized using an XY graphic digitizer to obtain the basic source data needed to generate the areal (or grid) data. The procedure consisted of digitizing the boundary lines of each delineated density patch on the map using a line-follower device consisting of a cursor with an actuating switch. As the operator followed the patch boundary, the crosshairs of the cursor were kept on the line; the switch on the cursor was activated at a sufficient number of points along the boundary line to define its sinuosity. Each time the switch was triggered, x- and y-coordinates were recorded, and a patch descriptor (code) was entered through an input keyboard. The data on each patch were placed directly on a magnetic tape for storage.

26. The digitized and coded map data were placed in a computer disc file and plotted at the same scale as the original digitized map. The plotted map was then overlaid to the base map to check for digitizing and coding errors and to determine how well the patch boundary was delineated. The digitized data on the composite vegetation map were then input into the computer program VEGGRID to produce a gridded array of plant density data. This program merely reads the digitized data and assigns a value to each designated 2-ft grid point falling within the designated patch boundary. The composite grid array is produced and is checked by using a computer printout of the grid array. The computer files were then used as input to the HARVEST model.

Selection of Harvesting System and Determination of Performance Specifications

27. Since the area to be harvested in Buffalo Lake was large, it was decided to simulate only large-size harvesters. Only these large-size harvesters could complete operations in a timely manner. Harvesting systems

manufactured by the Aquamarine Corporation have received the most widespread usage (Cannellos 1981). Aquamarine harvesters are owned by many contractors, governmental agencies, and lake associations. Therefore, for the purposes of this simulation, the two largest systems manufactured by the Aquamarine Corporation were simulated.

28. These two harvesters were the H8-650 (8-ft cutter width, 650-cu-ft storage capacity) and the H-400 (6-ft cutter width, 400-cu-ft storage capacity). The only transport unit manufactured by Aquamarine is the T-650 (650-cu-ft capacity), which can be used with either harvester. Since WES has conducted extensive performance tests on the Aqua-trio system (H8-650 harvester, T-650 transporter, and S-650 take-out conveyer) in Florida (Culpepper and Decell 1978), required performance data inputs for the H8-650 harvester and the T-650 transporter were determined based on data obtained during these tests. Contact was made with Aquamarine engineers to determine significant differences between the H8-650 and H-400 harvesters which might result in performance differences. Performance specifications for the H-400 harvester were then estimated based on the H8-650 data and the differences between the harvesters. Table 4 contains a summary of performance data for each unit of equipment composing the harvesting systems.* These data are used as input to the HARVEST model.

Simulation of Harvesting Operations

29. The WES HARVEST model simulates each important step in harvesting aquatic plants during a mechanical control operation. The model inputs include site dimensions, plant density (in gridded array form), distance to the nearest shore disposal site, and mechanical and performance specifications of the harvesting system. In the model, the harvester is assumed to be operated such that a plant collection rate, as close as possible to the harvester's maximum throughput, is maintained by varying harvester speed and cutter width up to their respective maximums. An overlap of 2 ft between successive passes is assumed. When the harvester's plant-holding capacity is full, harvesting operations cease and the material is then off-loaded to a transport unit.

* Throughout this report, the term "harvesting system" refers to a harvester and any nonharvesting equipment which assists, i.e., a transport unit (when used).

(If no transport units are used, the harvester acts as a transport unit.) Harvesting operations are then resumed, and the filled transport unit maneuvers directly to the site corner nearest the shore disposal area and then along a straight-line path to the disposal area. The transported material is off-loaded, and the transporter unit then returns to the harvest site. When the harvester is again loaded to capacity, it off-loads to a transport unit, if available; if the transport unit has not yet returned from the disposal site, the loaded harvester waits until the unloaded transport returns. After initial harvesting of the site is complete, the harvester begins cleanup operations consisting of full-speed, full-width passes over half of the swaths originally harvested. The operation is complete when the last partial load of harvested plant material is off-loaded at the disposal site. The model determines (a) the time spent by each piece of equipment in each mode of its operation, and (b) the mass of material handled. A more thorough discussion of the WES HARVEST model is available in papers by Hutto (1981, 1982).

30. In the present simulation study, HARVEST outputs the following statistics on time, loads, mass and production, and efficiency rates for each site simulated:

TOTAL. Total amount of time (minutes) required to perform the entire mechanical control operation at a harvest site.

WORK. Total amount of time (minutes) the harvester actually spends in the harvesting function.

TURN. Total amount of time (minutes) the harvester spends turning around between successive passes through a harvest site.

WAIT. Total amount of time (minutes) the loaded harvester spends waiting for a transport unit on which to off-load (when a transport unit is used), or the time the harvester spends acting as a transport unit when none are used.

CHANGE. Total amount of time (minutes) the harvester spends coupled to a transport unit while off-loading harvested plant material.

CLEANUP (CLEAN). Total amount of time (minutes) required for the harvester to perform the cleanup operations.

TRANSPORT (TRANS). Total amount of time (minutes) spent by the transport unit (or the harvester when no transport units are used) hauling harvested plant material to the disposal site, off-loading, and returning to the 'arvest site.

LOADS. Number of loads of harvested plant material taken to the disposal site.

MASS. Tonnage of plant material harvested.

SWATHS. Number of passes through a harvest site made by the harvester during harvesting operations.

AREAL RATE (RATE_A). Acreage harvested divided by TOTAL (acres/hour).

MASS RATE (RATE_M). MASS divided by TOTAL (tons/hour).

EFFECTIVE USE (EFFIC_H). The percentage of TOTAL time spent by the harvester in WORK and CLEANUP operations.

31. The results of the HARVEST simulations for Buffalo Lake are presented in Tables 5-12 as follows:

Table	Harvester	Transporter	Time
5	H-400	None	Early summer
6	↓	None	Late summer
7	↓	One	Early summer
8	↓	One	Late summer
9	H8-650	None	Early summer
10	↓	None	Late summer
11	↓	One	Early summer
12	↓	One	Late summer

As shown above, for each of the harvesting sites established during early and late summer periods (Table 3), harvesting operations are simulated using the Aquamarine H8-650 and H-400 harvesters working alone and with the support of one T-650 transport unit. Only full depth was simulated because the lake is so shallow and because accurate vertical biomass distributions were not determined for each plant species/patch type combination.

32. Several factors need to be considered when interpreting the HARVEST model predictions:

a. HARVEST determines the minimum time of operating a harvesting system. The actual field operations may not be quite so efficient.

b. No machine downtime is allowed during the harvesting operations. While this is not of significance in estimating costs for contract harvesting since only working time is paid, it is of importance in estimation of how long an operation will take. To estimate the total time required for an operation, 30 percent should be added to the operational time predicted by HARVEST.

c. The HARVEST model does not predict for the time required to haul the plant material from the shore disposal site to a remote upland disposal site. If upland disposal is required, then additional time and costs will be involved in the mechanical control operation.

PART III: RESULTS AND ANALYSIS

Aquatic Plant Distribution and Biomass

Species composition and distribution

33. As indicated in Table 1, a large number of aquatic plant species were encountered in the lake. With the exception of *Vallisneria americana* beds, aquatic plant beds at nuisance level densities rarely contained only a single species; dense beds commonly consisted of two or more species each at high-density levels.

34. *Ceratophyllum demersum* was by far the most widespread species; greatest densities were observed in the western half of the study area (between Montello and Packwaukee). *Vallisneria americana*, the second most abundant species, was found at very high biomass densities generally in the middle portion of the lake; however, it did not appear to create as much of a problem as *Ceratophyllum demersum* since most of its biomass was toward the bottom of the water column. Beds of *Vallisneria* tended to be almost monospecific and to occur in deeper water (4-ft depth or more), with water current frequently apparent. By late summer, the dense beds of *Vallisneria* had reached near the water surface, and extensive floating mats of *Vallisneria* leaves, presumably severed by boat propellers, had drifted about in the lake collecting in windrows and on surface-matted plants. *Elodea canadensis* was widespread throughout the lake and was commonly a secondary dominant species in weed beds dominated by *Ceratophyllum*. Dense weed beds dominated by *Myriophyllum exalbescens* were found in the eastern third of the study area. Other plant species occurred at nuisance-level densities only in localized areas, or were relatively sparse and did not create a problem as did the four dominant species.

35. In terms of species distribution and composition, several changes were apparent between sampling periods. While *Ceratophyllum demersum* and *Vallisneria americana* were observed as dominants during the early summer sampling, they exhibited far greater dominance, in terms of density, during the late summer sampling period. *Najas flexilis* was detected only in trace amounts during the early summer sampling; by late summer, dense *Najas flexilis* beds were found in a large area along the south shore of the east end of the lake. During the early summer sampling period, epiphytic growth on the plants

was minimal. By late summer, plants throughout the lake contained thick coatings of filamentous algae which would appreciably contribute to harvestable plant mass.

Distribution of aquatic plant beds

36. The portion of the lake infested with aquatic plants and the degree of infestation were estimated based upon the location and width of plant beds determined during each field sampling. The distance along each transect for which each particular patch type was observed is illustrated for each sampling period in Figure 3. The ratio of transect length by patch type to total transect length is used as an approximation of the percent of the area occupied by each patch type near each transect and for the entire area studied.

37. In early summer, the eastern half of the study area was relatively free of nuisance-level plant growth, with surface-topped plant growth covering only approximately 21 percent of that area.* Aquatic plant growth visible below the water surface covered approximately 52 percent of this area, and no plant growth was visible in the remaining 27 percent of the area. During the same period, the western half of the study area showed much greater infestation levels: approximately 57 percent of that area contained surface-topped plant growth. Visible submerged growth and no visible growth accounted for approximately 29 percent and 14 percent, respectively, of that area. Overall, surface-topped and submerged plant growth accounted for 35 percent (520 acres) and 45 percent (670 acres), respectively, of the entire study area.

38. By late summer, surface-topped plant growth had covered 50 percent (740 acres) of the entire study area, with submerged plant growth visible in another 40 percent of the area. In the eastern half of the lake, surface-topped plant growth reached an areal coverage of approximately 36 percent; submerged growth was visible in approximately 54 percent of this area. In the western half of the study area, surface-topped growth reached an areal coverage of approximately 65 percent and submerged growth was visible in another 24 percent of this area.

39. Between the early and late summer samplings the Buffalo Lake Property Owners Association contracted with the harvesting company for a week's time to cut trails in the lake. This may in part be responsible for an

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* All estimates of areal coverage of plant growth are based on the approximation procedure described in paragraph 36 and illustrated in Figure 3.

apparent decrease in infested areas along some transects between the early and late summer samplings (Figure 3).

40. Contact was made with several resort and property owners along Buffalo Lake to determine how plant growth during the summer of 1982 compared with other years. All those contacted responded that plant growth was heavier in other years and that it was quite unusual to have a large area of open water in the eastern half of the lake.

Vertical biomass distribution

41. Figure 5 illustrates the vertical biomass distribution of three individual weed beds each dominated by one of the most abundant plant species. The weed bed dominated by *Myriophyllum exalbescens* tended to have greatest density in the upper part of the water column, particularly during the late summer period. The *Vallisneria americana* weed bed had greatest biomass toward the bottom of the water column. Plant height increased over the summer, as did density in all layers. During the early summer period, the *Ceratophyllum-demersum*-dominated weed bed had greatest density toward the bottom of the water column; by late summer, the greatest portion of the biomass was in the surface layer.

42. It should be noted that these data reflect only single weed beds. While these beds were selected because they were judged to be typical of dense weed beds dominated by the major species, weed beds of the dominant species occurred at a number of densities and depths and in numerous combinations with subordinate species. It was, therefore, concluded that generalized vertical profiles could not be developed for the lake as a whole and it was not practical, within the time available, to determine vertical distribution for each individual combination of species, depth, and density level.

Harvestable biomass density

43. Harvestable densities of the actual harvest sites are listed in Table 3. Within the treatment area, a total of 165 acres at a mean density of 5.9 tons/acre would require harvesting by early summer, and a total of 213 acres at a mean density 7.9 tons/acre would require harvesting by late summer. From Table 2 it can be seen that the mean density of the surface-topped plant growth showed a twofold increase between early and late summer, in addition to a 43 percent areal increase (Figure 3).

Simulation Results

Operational times

44. A comparison of total system time (TOTAL), subdivided into WORK, WAIT, CLEAN, and OTHER time components, for early and late summer periods is illustrated in Figures 7 and 8, respectively. The predicted operational times for both systems were less in the early summer, when total harvestable mass was 972 tons, than in the late summer when total harvestable mass was 1677 tons. Addition of a transport unit considerably reduced operational times for both systems during both summer periods, although it should be noted that the system now consists of two machines instead of one. Further, during both summer periods, the H8-650 harvester working alone required less time to effect control operations than the H-400 harvester working alone or with a transport unit.

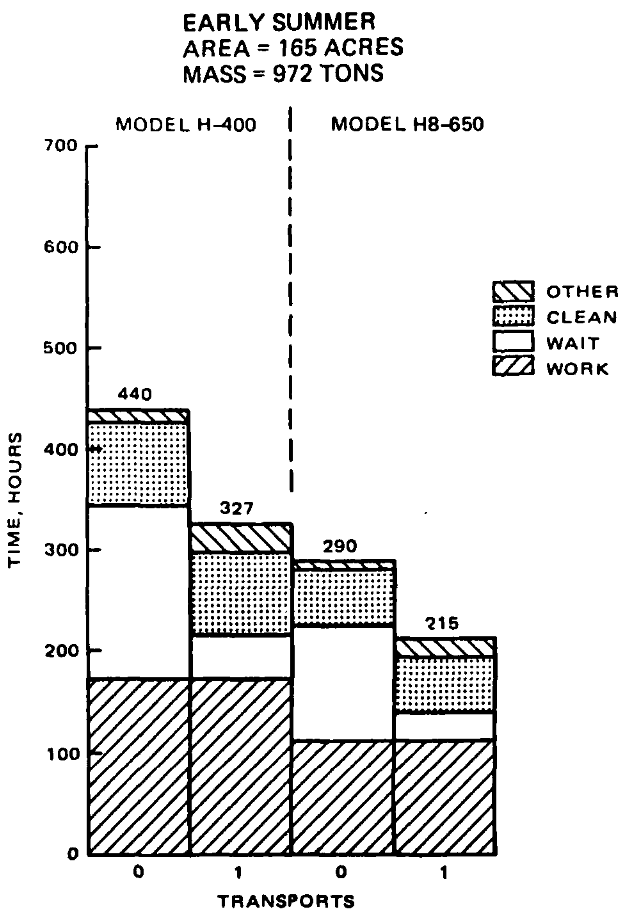


Figure 7. Predicted operational times, early summer

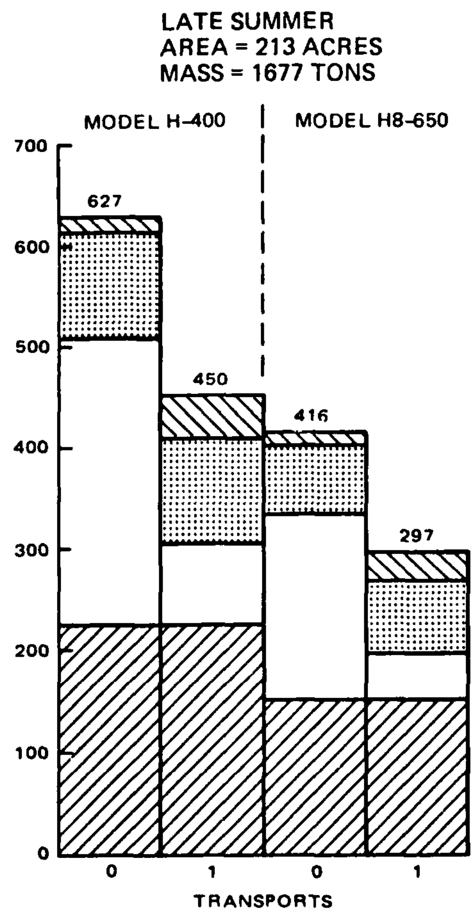


Figure 8. Predicted operational times, late summer

45. Paragraph 30 summarized the simulations performed at each harvesting site. At all simulated harvesting sites, the harvesters operated at maximum effective cutter width (full cutter width minus 2 ft for overlap) and most frequently at full speed. Based on the cutter width and throughput values for the harvesters simulated, HARVEST would simulate the H8-650 and H-400 harvesters as running at full speed in all plant densities below 12.4 tons/acre and 13.9 tons/acre, respectively. Consequently, the harvesters are predicted to run at full speed in all early summer harvesting sites but to be required to reduce harvesting speed slightly in several of the late summer harvesting sites (Table 3). Thus, maximum harvester speed and/or effective cutter width are the factors which limit the harvester's collection rate.

Production rates and efficiency

46. Summaries of the AREAL RATE, MASS RATE, and EFFECTIVE USE are presented by period and system in Table 13. The larger H8-650 harvester has greater production rates than the smaller H-400 harvester, and a harvester serviced by a transport unit will have greater production rates than one working alone. Between early and late summer periods, AREAL RATES and EFFECTIVE USE within harvesting systems decreased while MASS RATE increased. This reflects the greater densities occurring later in the summer, slowing the areal rate of harvesting but increasing the mass rate of harvesting. During the late summer period, the relatively shorter amount of time required to collect a load resulted in more WAIT time and thus a lower EFFECTIVE USE percentage.

47. Actual production rate values reported by others (McGehee 1979, Cannellos 1981, Wile and Hitchin 1977, and Culpepper and Decell 1978) are all within the range of rates predicted in this simulation study.

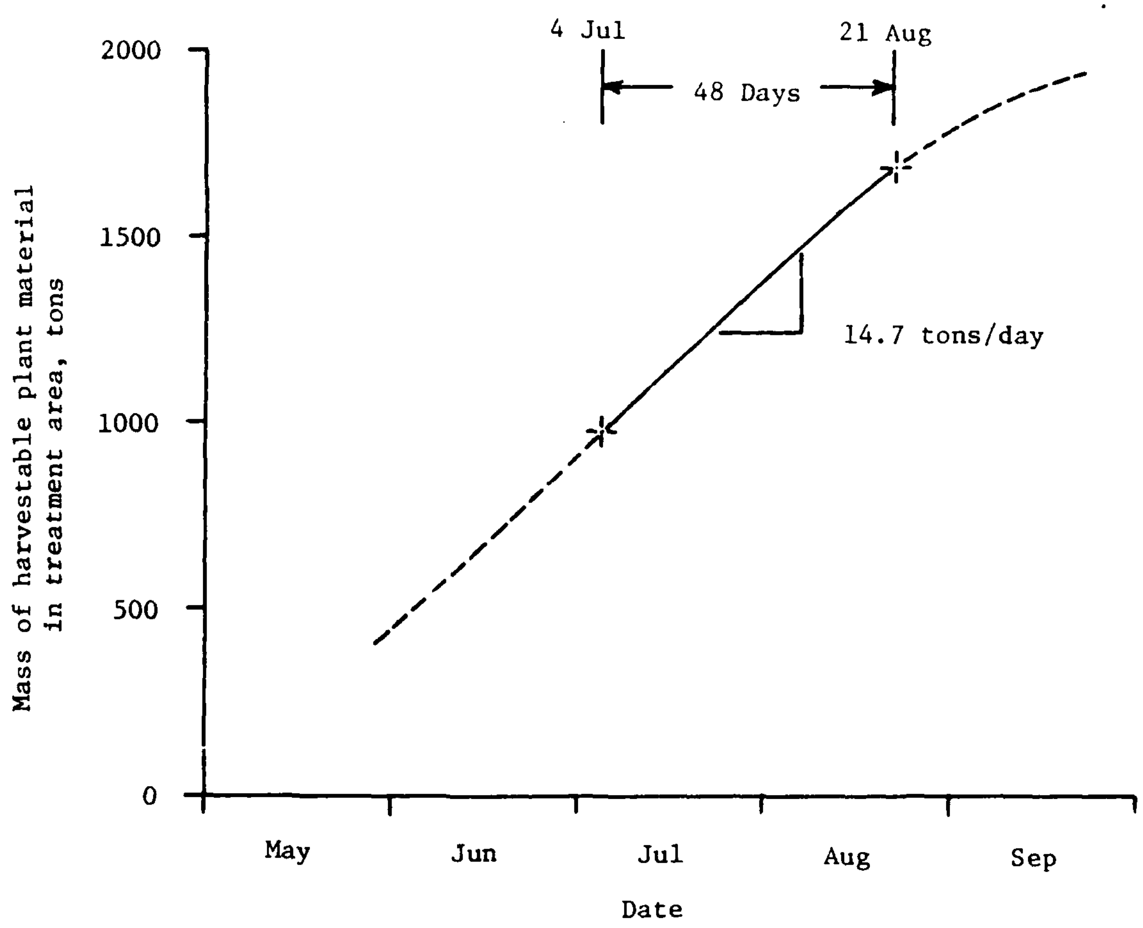
48. Examination of the individual best and worst production rates and efficiencies (Table 3) reveals how harvest site parameters affect production and efficiency:

a. Highest AREAL RATES and EFFECTIVE USE occurred at harvest sites with low plant density and short disposal site distance. Conversely, lowest AREAL RATES and EFFECTIVE USE occurred at harvest sites with high plant density and long disposal site distance.

b. Highest MASS RATES occurred at harvest sites with high plant density and short disposal site distances; lowest MASS RATES occurred at harvest sites with low plant density and long disposal site distance.

Timing

49. Between the two WES sampling periods, the mass of harvestable plant material in the treatment area (Figure 6) increased by 705 tons. A curve depicting this increase in mass is illustrated in Figure 9; the assumption is



NOTE: Harvestable treatment area is defined based on criteria stated in paragraph 23. The treatment area is the 276-acre area illustrated in Figure 6.

Figure 9. Mass of harvestable plant material within treatment area of Buffalo Lake during the 1982 growing season

made that the mass increased at a constant rate between samplings. No assumptions are made concerning this mass before the early sampling period or after the late sampling period, although these respective sampling periods are near

the beginning and end of the growing season. The rate of increase between samplings is 14.7 tons/day (Figure 9).

50. If a single harvesting system is scheduled to operate 10 hr/day and 6 days/week, the total operation time, as predicted by HARVEST, would range from 3.5 to 7.3 weeks for early summer operations and 5.0 to 10.5 weeks for late summer operations depending on the individual harvesting system used. This does not include downtime which could easily increase the duration of the control operation by 30 percent. Given that harvestable mass increases at a rate of 103 tons/week (7 × 14.7 tons/day), the total duration would need to be considerably less than those estimated above in order for the actual operational times to be close to those predicted. Additionally, in an extended duration operation, the areas harvested at the start of the operation may be in need of repeated harvesting before the entire treatment area has been harvested once. For these reasons, it is recommended that control operations be planned such that they can be completed within approximately 3 weeks or less.

51. An important aspect of operational planning not considered in this study is the determination of when and how many times harvesting operations are needed to keep plants in the treatment area below the nuisance level. Harvesting operations were simulated at two times, and predicted operational times for the early period were less because the harvestable plant mass was less. However, the effects of early summer harvesting on late summer plant conditions are not known; predictive capabilities do not yet exist which could determine this. Thus, to determine the harvesting schedule (when and how many times to harvest) that would minimize operational costs and maximize control affected, field studies would need to be conducted in Buffalo Lake, concurrent with the first year's operations. The optimum schedule determined from the study could then be used in subsequent years.

Cost estimation and system selection

52. Selection of a particular harvesting system or systems is necessarily a decision based on costs and not system production or efficiency statistics. To select the most cost-effective harvesting system(s), hourly operational costs for each piece of equipment with an operator must first be determined. These costs would then be multiplied by the respective TOTAL times predicted for each system. As a purely hypothetical example, assume that the rental rates (with operator) for an H-400 harvester, a T-650

transporter, and an H8-650 harvester are \$80/hr, \$100/hr, and \$110/hr, respectively. Then apply these rates to the TOTAL operational times predicted for the early summer (Table 14). Using these assumed cost figures, the H8-650 harvester working alone would be the most cost-effective system. To complete operations in 3 weeks or less, two H8-650 harvesters would be required to operate simultaneously.

$$\text{Number of Systems Required} = \frac{\text{TOTAL (System Hours)} \times \text{Downtime Correction Factor}}{\text{Work Schedule (hr/week)}} \Big/ \text{Desired Time Limit of Operations (weeks)}$$

$$= \frac{290 \text{ hr} \times 1.3}{60 \text{ hr/week}} \Big/ 3 \text{ weeks}$$

$$= 2.09\ (\sim 2)$$

53. The important point here is that, although the addition of a transport increases harvesting system production and efficiency (Table 13), this increase is proportionally less than the increased cost of adding a transport unit. The use of different hourly rates could result in another equipment mix (system) being the most cost-effective; however, hourly rates of a T-650 transport unit will probably always be as much or more than an H-400 harvester and should be close to the rate for an H8-650 harvester.

PART IV: SUMMARY AND RECOMMENDATIONS

Summary

54. Aquatic plant density studies on Buffalo Lake showed a severe and extensive lake-wide infestation. Surface-topped plant growth between Montello and Packwaukee, i.e. the treatment area, covered 520 acres and 740 acres in early and later summer periods, respectively (paragraphs 37 and 38).

55. Twenty different plant species were encountered in the lake. Four of them accounted for most of the nuisance-level plant growth. In order of importance, these are: *Ceratophyllum demersum*, *Vallisneria americana*, *Elodea canadensis*, and *Myriophyllum exalbescens* (paragraphs 33-35).

56. To maintain the treatment areas, i.e. the 276 acres of parallel boat trails and connecting trails, at below nuisance level plant densities would require harvesting 165 acres at an overall density of 5.9 tons/acre in early summer, or harvesting 213 acres at an average density of 7.9 tons/acre by late summer (paragraph 43).

57. Total simulated system times required for the Aquamarine H8-650 and the H-400 harvesters working alone and with a T-650 transporter to perform the control operation are as follows (Figures 7 and 8):

Harvester	Transports	Period	Total Hours
H-400	0	Early summer	440
H-400	1	Early summer	327
H-400	0	Late summer	627
H-400	1	Late summer	450
H8-650	0	Early summer	290
H8-650	1	Early summer	215
H8-650	0	Late summer	416
H8-650	1	Late summer	297

58. A procedure for planning mechanical control operations is presented in paragraphs 49-53. Hypothetical hourly equipment cost rates were used to determine the most cost-effective harvesting system for the early summer (June) harvesting period in Buffalo Lake.

Recommendations

59. Prior to implementing mechanical control operations at Buffalo Lake, it is recommended that procedures such as described and demonstrated in this study be used to select the most cost-effective equipment mix for the aquatic plant conditions that will be expected to occur during the designated operational time(s).

60. It is also recommended that tests be conducted to determine the effects of early summer harvesting in Buffalo Lake on late summer plant conditions. This will allow for improved planning of harvesting operations for mechanical control of the lake.

REFERENCES

Cannellos, G. 1981. "Aquatic Plants and Mechanical Methods for Their Control," U. S. Environmental Protection Agency Contract No. 68-01-5965, The Mitre Corp., McLean, Va.

Correll, D. S., and Correll, H. B. 1972. "Aquatic and Wetland Plants of the Southwestern United States," U. S. Environmental Protection Agency Water Pollution Control Research Series 16030 DNL 01/72, Washington, D. C.

Culpepper, M. M., and Decell, J. L. 1978. "Mechanical Harvesting of Aquatic Plants: Field Evaluation of the Aqua-trio System," Volumes I and II, Technical Report A-78-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Edmondson, W. T., ed. 1959. Freshwater Biology, John Wiley and Sons, New York.

Fassett, N. C. 1974. A Manual of Aquatic Plants, University of Wisconsin Press, Madison, Wis.

Headquarters, Department of the Army. 1979. "Remote Sensing Applications Guide," Engineering Pamphlet 70-1-1, Washington, D. C.

Hutto, T. D. 1981. "Prediction of Equipment Performance for Optimal Mechanical Harvesting of Submerged Aquatic Plants, Proceedings, 15th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, Miscellaneous Paper A-81-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 197-213.

__________ 1982. "Simulation Modeling of Mechanical Control Systems," Proceedings 16th Annual Meeting, Aquatic Plant Control Research Planning and Operations Review, Miscellaneous Paper A-82-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss., pp 33-50.

Hutto, T. D., and West, H. W. 1983. "Evaluation of LIMNOS Mechanical Harvesting System" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Leonard, J. M. 1983. "Handbook for Obtaining and Using Aerial Photography to Map Aquatic Plant Distribution" (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

McGehee, J. T. 1979. "Mechanical Hydrilla Control in Orange Lake, Florida," Journal of Aquatic Plant Management, Vol 17, pp 58-61.

Prescott, G. W. 1969. The Aquatic Plants, Wm. C. Brown Co., Publishers, Dubuque, Iowa.

Sabol, B. M. 1983. "Development and Use of the WES Hydraulically Operated Submerged Aquatic Plant Sampler," ASTM Special Technical Publication (in press).

U. S. Army Engineer District, St. Paul. 1980. "Aquatic Plant Control, Buffalo Lake, Wisconsin," draft reconnaissance report, St. Paul, Minn.

Wile, I., and Hitchin, G. 1977. "An Assessment of the Practical and Environmental Implications of Mechanical Harvesting of Aquatic Vegetation in Southern Chemung Lake," Ministry of the Environment, Ontario, Canada.

Table 1

Aquatic Plant Species Encountered in Buffalo Lake During Summer 1982, in Relative Order of Abundance

Scientific Name	Common Name	Distribution	Plant Type
Ceratophyllum demersum	Coontail	High densities over widespread area	Submerged, rootless
Vallisneria americana	Wild celery	High densities over widespread area	Submerged, bottom rooted
Elodea canadensis	Waterweed	High densities over widespread area	Submerged, bottom rooted
Myriophyllum exalbescens	Watermilfoil	High densities over widespread area	Submerged, bottom rooted
Heteranthera dubia	Waterstargrass	Medium densities over widespread area	Submerged, bottom rooted
Potamogeton pectinatus	Sago pondweed	Medium densities over widespread area	Submerged, bottom rooted
P. praelongus	Pondweed	High densities in localized areas	Submerged, bottom rooted
P. crispus	Curly leaf pondweed	High densities in localized areas	Submerged, bottom rooted
Najas flexilis	Common naiad	High densities in localized areas	Submerged, bottom rooted
Lemna minor	Common duckweed	Widely distributed	Floating
Spirodela oligoriza	Giant duckweed	Widely distributed	Floating
Lemna trisulca	Duckweed	Widely distributed	Floating
Wolffia punctata	Watermeal	Widely distributed	Floating
Potamogeton richardsonii	Pondweed	Sparse density in localized areas	Submerged, bottom rooted
P. berchtoldii	Pondweed	Sparse density in localized areas	Submerged, bottom rooted
Chara sp.	Musk grass	Sparse density in localized areas	Submerged, bottom rooted
Nelumbo lutea	American lotus	High density in a single area	Emersed, bottom rooted
Nymphaea odorata	Fragrant waterlily	Sparse density in localized areas	Emersed, bottom rooted
Nuphar luteum	Spatterdock	Sparse density in localized areas	Emersed, bottom rooted
Potamogeton nodosus	American pondweed	Trace amounts in a single area	Submerged, bottom rooted

Table 2

Harvestable Density (Tons/Acre) of Aquatic Plants by Patch Type and Sampling Period

Patch Type	Mean	N*	Standard Error	Minimum	Maximum
			Early Summer		
Surface-topped plant growth	6.32	89	0.59	0	25.11
Submerged growth visible	2.30	87	0.32	0	11.98
No growth visible	0.42	38	0.11	0	3.54
			Late Summer		
Surface-topped plant growth	12.64	111	0.88	0	42.29
Submerged growth visible	2.55	74	0.43	0	18.30
No growth visible	0.07	25	0.04	0	0.82

* N = number of replicates.

Table 3

Inventory of Harvest Sites

Designation*	Dimensions ft x	Dimensions ft y	Area acres	Nearest Disposal Site No.	Nearest Disposal Site Distance, ft	Harvestable Density, tons/acre
			Early Summer			
EM1A	1340	150	4.61	1	115	3.1
EM1B	958	150	3.30	1	3762	1.8
EM5	2170	150	7.47	3	713	7.2
EM6	1596	150	5.50	3	1511	2.2
EM7	2038	150	7.02	4	1826	4.8
EM9	2026	150	6.98	4	1826	2.9
EM11	1970	150	6.78	5	800	4.0
EM12	1454	150	5.01	5	1655	2.4
EM13	2570	150	8.85	5	800	7.8
EM14	2600	150	8.95	5	1655	2.8
EM15	2754	150	9.48	6	428	10.4
EM16	2768	150	9.53	6	913	3.8
EM17	5822	150	20.05	6	428	9.1
EM18	5822	150	20.05	6	913	4.0
EM19A	3044	150	10.48	7	2936	3.2
EM19B	1482	150	5.10	7	1112	2.7
EM20	4290	150	14.77	7	1739	6.3
EC9	628	100	1.44	5	940	3.9
EC10	742	100	1.70	5	2682	3.9
EC11	314	100	0.72	6	600	6.9

(Continued)

* The characters in the site designation code represent the following: 1st letter represents sampling period: E = early summer, L = late summer; 2nd letter represents channel type: M = main channel, 150 ft wide parallel to shore; C = connector channel, 100 ft wide, perpendicular to shore. Number represents specific treatment areas by channel type (see Figure 6). Last letter designates individual treatment areas which were harvested as two sites: A = east site, B = west site.

(Sheet 1 of 3)

Table 3 (Continued)

Designation	Dimensions ft x	Dimensions ft y	Area acres	Nearest Disposal Site No.	Nearest Disposal Site Distance, ft	Harvestable Density, tons/acre
			Early Summer (Continued)			
EC12	300	100	0.69	6	2283	7.2
EC13	428	100	0.98	6	4650	6.6
EC14	1028	100	2.36	7	4600	8.8
EC15	1142	100	2.62	7	2112	2.7
EC16	314	100	0.72	7	257	2.9
		Total	165.16		Mean**	5.9
			Late Summer			
LM1A	1310	150	4.51	1	142	5.5
LM1B	2426	150	8.35	1	2124	4.2
LM3	1450	150	4.99	3	2180	4.0
LM4	2460	150	8.47	3	1310	6.8
LM5	1010	150	3.48	3	1947	14.1
LM6	3170	150	10.92	3	1310	11.7
LM7	3000	150	10.33	4	1826	5.5
LM8	3328	150	11.46	4	514	6.7
LM9	2026	150	6.98	4	1826	9.0
LM10	1248	150	4.30	4	920	4.5
LM11	1970	150	6.78	5	800	12.9
LM12	1740	150	5.99	5	1655	10.2
LM13	2570	150	8.85	5	800	4.3
LM14	2600	150	8.95	5	1655	14.3
LM15	2754	150	9.48	6	428	3.9
LM16	2496	150	8.60	6	913	12.1
LM17A	2390	150	8.23	6	428	12.9

(Continued)

** Area weighted mean.

Table 3 (Concluded)

Designation	Dimensions ft x	Dimensions ft y	Area acres	Nearest Disposal Site No.	Nearest Disposal Site Distance, ft	Harvestable Density, tons/acre
			Late Summer (Continued)			
LM17B	3010	150	10.37	6	2956	14.7
LM18A	850	150	2.93	6	913	5.8
LM18B	4284	150	14.75	6	2000	4.3
LM19	5168	150	17.80	7	584	6.3
LM20	5862	150	20.18	7	600	5.8
LC1	336	100	0.77	1	828	2.5
LC3	742	100	1.70	3	2112	5.6
LC4	886	100	2.03	3	400	6.3
LC8	336	100	0.77	5	2340	10.5
LC9	628	100	1.44	5	940	8.0
LC10	620	100	1.42	5	2682	8.1
LC13	428	100	0.98	6	4650	8.4
LC14	768	100	1.76	7	4600	14.0
LC15	1010	100	2.32	7	2112	11.9
LC16	1228	100	2.82	7	628	3.3
		Total	212.71		Mean**	7.9

** Area weighted mean.

(Sheet 3 of 3)

Table 4

Harvesting System Performance Inputs Used in Simulation

Specification	Harvester System* H-400	Harvester System* H8-650
Cutter width, ft**	6.0	8.0
Maximum working speed of harvester, ft/min	176	176
Harvester throughput, tons/hr	13.5†	18
Harvester turn time, min	0.5	0.5
Transport used	T-650	T-650
Transport change time at harvester, min	2.3	2.3
Transport capacity volume, cu ft	400††	650
Transport capacity weight, tons‡	2.5	4.0
Transport speed, ft/min		
Empty	264	264
Full	230	230
Unloading rate of transport, tons/min	1.5	1.5
Docking time, min ‡‡	1.0	1.0

* Both systems are manufactured by Aquamarine Corp., Waukesha, Wis.
** Width is reduced by 2 ft in simulation to allow for overlap.
† Based on reduced conveyor belt width of H-400.
†† Based on limit of H-400 capacity.
‡ Assuming a stacked plant density of 12.2 pcf.
‡‡ Personal communication, Mr. Art Reinhardt, President, Wisconsin Lake Harvesters, Menomonee Falls, Wis.

TABLE 5. SIMULATION OF H-400 HARVESTER WITH NO TRANSPORTS IN EARLY SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
EC09	179.9	89.8	12.0	27.6	43.1	0	35.1	2.2	5.5	25	0.48	1.8	73.9
EC10	240.2	105.7	12.0	55.7	50.7	0	71.8	2.6	6.5	25	0.43	1.6	65.1
EC11	93.9	44.3	12.0	9.7	21.3	0	16.3	1.9	4.9	25	0.46	3.1	69.9
EC12	102.4	36.9	12.0	22.9	17.7	0	35.7	1.7	4.2	25	0.35	2.5	53.3
EC13	208.0	60.8	12.0	83.4	29.2	0	106.1	2.6	6.4	25	0.28	1.8	43.3
EC14	608.0	146.0	12.0	356.8	78.1	0	379.8	8.2	20.4	25	0.23	2.0	35.5
EC15	318.6	162.5	12.0	50.0	78.0	0	66.2	2.8	7.0	25	0.49	1.3	75.5
EC16	84.1	45.4	12.0	0.0	21.8	0	4.8	0.8	2.1	25	0.52	1.5	79.9
EM01A	497.5	288.4	18.5	45.4	136.6	0	53.9	5.8	14.6	38	0.55	1.8	85.4
EM01B	417.5	206.4	18.5	74.4	97.8	0	94.8	2.4	5.9	38	0.47	0.9	72.9
EM05	1123.9	468.1	18.5	401.5	221.7	0	415.5	21.7	54.1	38	0.40	2.9	61.4
EM06	626.7	335.1	18.5	98.7	158.7	0	114.4	4.9	12.3	38	0.51	1.2	78.8
EM07	996.4	429.2	18.5	335.8	203.3	0	345.3	13.6	34.0	38	0.41	2.0	63.5
EM09	881.8	437.9	18.5	201.4	207.4	0	208.0	8.3	20.7	38	0.48	1.4	73.2
EM11	830.5	424.9	18.5	179.1	201.3	0	185.8	10.9	27.3	38	0.49	2.0	75.4
EM12	583.3	310.9	18.5	96.2	147.3	0	106.6	5.0	12.4	38	0.51	1.3	78.6
EM13	1398.6	554.5	18.5	548.9	262.6	0	563.0	28.1	70.2	38	0.38	3.0	58.4
EM14	1135.5	561.4	18.5	272.0	265.9	0	289.7	10.2	25.4	38	0.47	1.3	72.9
EM15	1591.0	594.2	18.5	693.6	281.4	0	696.8	40.0	100.1	38	0.36	3.8	55.0
EM16	1206.0	597.6	18.5	300.2	283.1	0	306.8	14.7	36.7	38	0.47	1.8	73.0
EM17	4033.4	1256.6	18.5	2135.5	595.2	0	2163.0	72.6	181.5	38	0.30	2.7	45.9
EM18	2932.7	1256.6	18.5	1032.1	595.2	0	1062.4	31.7	79.2	38	0.41	1.6	63.1
EM19A	3078.6	657.2	18.5	2076.2	311.3	0	2091.6	54.0	134.9	38	0.20	2.6	31.5
EM19B	571.5	317.0	18.5	79.3	150.1	0	85.9	5.6	14.1	38	0.53	1.5	81.7
EM20	2636.9	925.8	18.5	1243.3	438.5	0	1254.0	36.9	92.4	38	0.34	2.1	51.7

TABLE 6. SIMULATION OF H-400 WITH NO TRANSPORT IN LATE SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
LC01	90.7	48.3	12.0	0.0	23.2	0	7.3	0.7	1.9	25	0.52	1.3	78.8
LC03	250.0	105.4	12.0	67.8	50.6	0	82.0	3.7	9.4	25	0.41	2.2	62.4
LC04	255.4	126.1	12.0	50.8	60.5	0	56.8	5.0	12.6	25	0.47	3.0	73.1
LC08	157.0	44.9	12.0	67.1	21.5	0	78.6	3.2	7.9	25	0.27	3.0	42.3
LC09	204.2	89.2	12.0	52.0	42.8	0	60.2	4.5	11.3	25	0.42	3.3	64.6
LC10	275.3	93.8	12.0	108.8	45.0	0	124.6	4.6	11.5	25	0.33	2.5	50.4
LC13	249.3	60.8	12.0	126.1	29.2	0	147.3	3.2	8.0	25	0.24	1.9	36.1
LC14	590.1	109.9	12.0	391.5	52.4	0	415.8	9.6	24.1	25	0.18	2.4	27.5
LC15	484.2	142.6	12.0	245.8	68.4	0	261.2	10.8	26.9	25	0.29	3.3	43.6
LC16	320.0	174.4	12.0	40.0	83.7	0	49.8	3.7	9.1	25	0.53	1.7	80.7
LM01A	533.0	279.8	18.5	95.3	132.5	0	102.1	10.1	25.3	38	0.50	2.8	77.4
LM01B	1134.8	515.6	18.5	334.4	244.2	0	356.5	14.0	34.9	38	0.43	1.8	67.0
LM03	683.8	301.0	18.5	211.8	142.6	0	221.8	8.1	20.2	38	0.42	1.8	64.9
LM04	1313.4	518.2	18.5	523.8	245.4	0	531.3	23.4	58.6	38	0.38	2.8	58.1
LM05	819.6	237.9	18.5	446.2	102.3	0	460.9	19.8	49.4	38	0.25	3.6	41.5
LM06	2380.5	684.0	18.5	1333.1	324.0	0	1354.0	51.7	129.3	38	0.27	3.2	42.3
LM07	1656.0	648.6	18.5	671.8	307.2	0	681.6	22.7	56.8	38	0.37	2.0	57.7
LM08	1677.1	700.4	18.5	623.0	331.8	0	626.4	31.2	78.1	38	0.40	2.8	61.5
LM09	1331.8	437.9	18.5	651.1	207.4	0	668.0	25.4	63.4	38	0.31	2.8	48.5
LM10	529.5	266.9	18.5	106.4	126.4	0	117.8	7.8	19.4	38	0.48	2.2	74.3
LM11	1236.3	425.3	18.5	585.9	201.5	0	591.0	34.2	85.5	38	0.33	4.2	50.7
LM12	1147.9	376.5	18.5	564.8	178.4	0	574.5	24.7	61.7	38	0.31	3.2	48.3
LM13	1208.1	556.2	18.5	355.4	263.4	0	369.9	15.2	38.0	38	0.44	1.9	67.8
LM14	2373.6	680.0	18.5	1390.6	266.7	0	1408.4	52.2	130.5	38	0.23	3.3	39.9
LM15	1156.8	597.6	18.5	254.4	283.1	0	257.6	15.0	37.6	38	0.49	1.9	76.1
LM16	1672.6	558.2	18.5	834.0	255.3	0	840.6	41.7	104.3	38	0.31	3.7	48.6
LM17A	1456.8	533.4	18.5	651.8	239.7	0	665.2	42.6	106.4	38	0.33	4.4	53.1
LM17B	3425.0	685.7	18.5	2381.1	312.5	0	2408.3	61.7	154.3	38	0.18	2.7	29.1
LM18A	386.2	185.2	18.5	85.0	87.8	0	94.7	6.8	16.9	38	0.46	2.6	70.7
LM18B	2288.8	918.0	18.5	890.2	434.9	0	917.4	25.5	63.8	38	0.38	1.7	59.1
LM19	2955.1	1096.8	18.5	1315.9	519.5	0	1320.3	46.6	116.4	38	0.36	2.4	54.7
LM20	3353.4	1265.2	18.5	1465.6	599.3	0	1470.4	46.4	116.1	38	0.36	2.1	55.6

TABLE 7. SIMULATION OF H-400 WITH ONE TRANSPORT IN EARLY SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
EC09	157.0	89.8	12.0	0.0	43.1	4.6	29.9	2.2	5.5	25	0.55	2.1	84.6
EC10	196.3	105.7	12.0	7.2	50.7	4.6	60.6	2.6	6.5	25	0.52	2.0	79.7
EC11	86.5	44.3	12.0	0.0	21.3	2.3	13.0	1.9	4.9	25	0.50	3.4	75.8
EC12	81.8	36.9	12.0	0.0	17.7	2.3	26.3	1.7	4.2	25	0.44	3.1	66.7
EC13	147.0	60.8	12.0	17.7	29.2	4.6	88.1	2.6	6.4	25	0.40	2.6	61.2
EC14	446.0	146.0	12.0	176.5	70.1	18.4	358.6	8.2	20.4	25	0.32	2.7	48.5
EC15	273.2	162.5	12.0	0.0	78.0	4.6	54.6	2.8	7.0	25	0.58	1.5	88.0
EC16	86.4	45.4	12.0	0.0	21.8	2.3	4.8	0.8	2.1	25	0.51	1.4	77.8
EM01A	463.6	288.4	18.5	0.0	136.6	11.5	50.7	5.8	14.6	38	0.60	1.9	91.7
EM01B	347.7	206.4	18.5	0.0	97.8	4.6	80.3	2.4	5.9	38	0.57	1.0	87.5
EM05	776.8	468.1	18.5	6.2	221.7	48.3	409.0	21.6	54.1	38	0.58	4.2	88.8
EM06	537.2	335.1	18.5	0.0	158.7	9.2	103.3	4.9	12.3	38	0.60	1.4	91.9
EM07	690.5	429.2	18.5	0.0	203.3	29.9	332.8	13.6	34.0	38	0.59	3.0	91.6
EM09	698.8	437.9	18.5	0.0	207.4	18.4	207.5	8.3	20.7	38	0.60	1.7	92.3
EM11	674.3	424.9	18.5	0.0	201.3	23.0	177.3	10.9	27.3	38	0.60	2.4	92.9
EM12	496.3	310.9	18.5	0.0	147.3	9.2	97.1	5.0	12.4	38	0.60	1.5	92.3
EM13	938.0	554.4	18.5	23.9	262.6	64.4	555.3	28.1	70.2	38	0.56	4.5	87.1
EM14	886.5	561.4	18.5	0.0	265.9	23.0	276.2	10.[illegible]	25.4	38	0.60	1.7	93.3
EM15	1083.9	594.2	18.5	94.5	281.5	92.0	687.0	4[illegible].0	100.1	38	0.52	5.5	80.8
EM16	938.0	597.6	18.5	0.0	283.1	32.2	297.6	14.7	36.7	38	0.61	2.4	93.9
EM17	3015.6	1256.6	18.5	952.1	595.2	165.6	2150.7	72.6	181.5	38	0.40	3.6	61.4
EM18	1973.7	1256.6	18.5	1.8	595.2	71.3	1054.9	31.7	79.2	38	0.61	2.4	93.8
EM19A	2386.3	657.2	18.5	1262.0	311.3	121.9	2072.4	54.0	134.9	38	0.26	3.4	40.6
EM19B	503.7	317.0	18.5	0.0	150.1	11.5	80.6	5.6	14.1	38	0.60	1.7	92.7
EM20	1715.1	925.8	18.5	238.7	438.5	82.8	1231.5	36.9	92.4	38	0.52	3.2	79.5

TABLE 8. SIMULATION OF H-400 WITH ONE TRANSPORT IN LATE SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
LC01	93.0	48.3	12.0	0.0	23.2	2.3	7.2	0.8	1.9	25	0.50	1.2	76.9
LC03	189.1	105.4	12.0	0.0	50.6	6.9	72.1	3.7	9.4	25	0.54	3.0	82.5
LC04	216.1	126.1	12.0	0.0	60.5	11.5	52.0	5.0	12.6	25	0.56	3.5	86.3
LC08	100.6	44.9	12.0	3.7	21.5	6.9	69.4	3.2	7.9	25	0.43	4.7	66.0
LC09	161.4	89.2	12.0	0.0	42.8	9.2	55.2	4.5	11.3	25	0.54	4.2	81.8
LC10	181.5	93.8	12.0	5.8	45.0	9.2	112.9	4.6	11.5	25	0.50	3.8	76.5
LC13	165.8	60.8	12.0	35.8	29.2	6.9	129.4	3.2	8.0	25	0.36	2.9	54.3
LC14	464.1	109.9	12.0	244.8	52.4	20.7	396.0	9.6	24.1	25	0.23	3.1	35.0
LC15	361.4	142.6	12.0	100.0	68.4	23.0	251.8	10.8	26.9	25	0.38	4.5	58.4
LC16	286.8	174.4	12.0	0.0	83.7	6.9	43.5	3.6	9.1	25	0.59	1.9	90.0
LM01A	460.7	279.8	18.5	0.0	132.5	23.0	98.0	10.1	25.3	38	0.58	3.3	89.5
LM01B	835.1	515.6	18.5	4.7	244.2	29.9	341.9	14.0	34.9	38	0.59	2.5	91.0
LM03	490.5	301.0	18.5	0.0	142.6	18.4	209.8	8.1	20.2	38	0.59	2.5	90.4
LM04	876.0	518.2	18.5	33.4	245.4	52.9	525.2	23.4	58.6	38	0.57	4.0	87.2
LM05	566.1	237.9	18.5	149.1	102.3	43.7	452.1	19.8	49.4	38	0.36	5.2	60.1
LM06	1687.9	684.0	18.5	523.2	324.0	117.3	1346.3	51.7	129.3	38	0.39	4.6	59.7
LM07	1147.0	648.6	18.5	112.2	107.2	50.6	664.3	22.7	56.8	38	0.54	3.0	83.3
LM08	1127.9	700.4	18.5	2.6	331.8	71.3	621.0	31.2	78.1	38	0.59	4.2	91.5
LM09	884.6	437.9	18.5	146.4	207.4	57.5	658.4	25.4	63.4	38	0.47	4.3	72.9
LM10	439.2	266.9	18.5	0.0	126.4	16.1	113.4	7.8	19.4	38	0.58	2.6	89.5
LM11	792.4	425.3	18.5	63.9	201.5	78.2	581.3	34.2	85.5	38	0.51	6.5	79.1
LM12	764.2	376.5	18.5	125.9	178.4	55.2	566.9	24.7	61.7	38	0.47	4.8	72.6
LM13	892.8	556.2	18.5	5.7	263.4	34.5	357.3	15.2	38.0	38	0.60	2.6	91.8
LM14	1670.8	680.0	18.5	568.2	266.7	119.6	1399.6	52.2	130.5	38	0.32	4.7	56.7
LM15	937.8	597.6	18.5	0.8	283.1	34.5	245.9	15.0	37.6	38	0.61	2.4	93.9
LM16	1168.8	558.2	18.5	235.9	255.3	94.3	830.1	41.7	104.3	38	0.44	5.4	69.6
LM17A	1018.5	533.4	18.5	117.0	239.7	96.6	661.9	42.6	106.4	38	0.48	6.3	75.9
LM17B	2703.9	685.7	18.5	1519.6	312.5	140.3	2392.8	61.7	154.3	38	0.23	3.4	36.9
LM18A	333.6	185.3	18.5	18.5	87.8	13.8	89.6	6.8	16.9	38	0.53	3.0	81.9
LM18B	1527.2	918.0	18.5	71.0	434.9	57.5	902.2	25.5	63.8	38	0.58	2.5	88.6
LM19	2085.8	1096.8	18.5	340.8	519.5	105.8	1302.5	46.6	116.4	38	0.50	3.3	77.5
LM20	2350.6	1265.2	18.5	357.0	599.3	105.8	1450.2	46.5	116.1	38	0.52	3.0	79.3

TABLE 9. SIMULATION OF H8-650 WITH NO TRANSPORTS IN EARLY SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
EC09	118.3	61.0	8	12.1	28.7	0	20.5	1.4	5.6	17	0.74	2.9	75.8
EC10	157.9	71.9	8	27.2	33.8	0	44.2	1.7	6.6	17	0.65	2.5	66.9
EC11	67.2	30.1	8	9.6	14.2	0	14.8	1.2	5.0	17	0.64	4.4	65.9
EC12	79.1	25.1	8	23.3	11.8	0	34.2	1.1	4.3	17	0.45	3.3	46.6
EC13	135.6	41.3	8	43.1	19.4	0	66.8	1.6	6.5	17	0.43	2.9	44.8
EC14	406.6	99.3	8	229.2	46.7	0	252.6	5.2	20.8	17	0.35	3.1	35.9
EC15	213.5	110.5	8	26.2	52.0	0	43.0	1.8	7.2	17	0.74	2.0	76.1
EC16	58.2	30.9	8	0.0	14.5	0	4.8	0.5	2.1	17	0.76	2.2	78.0
EM01A	328.4	189.8	12	31.8	91.1	0	35.5	3.6	14.4	25	0.84	2.6	85.5
EM01B	271.4	135.8	12	40.3	65.2	0	58.4	1.5	5.9	25	0.73	1.3	74.1
EM05	710.1	308.0	12	236.8	147.8	0	242.3	13.4	53.6	25	0.63	4.5	64.2
EM06	417.2	220.5	12	71.6	105.8	0	78.9	3.0	12.1	25	0.77	1.7	78.2
EM07	661.8	282.4	12	214.6	135.5	0	231.9	8.4	33.6	25	0.62	3.0	63.1
EM09	603.5	288.1	12	156.8	138.3	0	165.2	5.1	20.5	25	0.69	2.0	70.7
EM11	545.4	279.5	12	105.1	134.2	0	119.7	6.7	27.0	25	0.75	3.0	75.9
EM12	387.6	204.5	12	59.9	98.2	0	72.9	3.1	12.2	25	0.77	1.9	78.1
EM13	907.2	364.8	12	349.7	175.1	0	355.3	17.3	69.2	25	0.58	4.6	59.5
EM14	788.9	369.3	12	221.5	177.3	0	230.3	6.3	25.1	25	0.68	1.9	69.3
EM15	1049.3	391.1	12	442.1	187.6	0	458.5	24.8	99.0	25	0.54	5.7	55.2
EM16	817.4	393.2	12	208.2	188.7	0	223.5	9.1	36.3	25	0.70	2.7	71.2
EM17	2613.7	826.7	12	1373.9	396.8	0	1378.2	45.4	181.5	25	0.46	4.2	46.8
EM18	1905.4	826.7	12	662.2	396.8	0	669.9	19.8	79.3	25	0.63	2.5	64.2
EM19A	2015.2	443.9	12	1326.4	207.5	0	1351.8	33.3	133.2	25	0.31	4.0	32.3
EM19B	384.7	208.5	12	51.4	100.1	0	64.1	3.5	13.9	25	0.79	2.2	80.2
EM20	1765.9	609.1	12	828.1	292.4	0	852.5	23.1	92.4	25	0.50	3.1	51.1

TABLE 10. SIMULATION OF H8-650 WITH NO TRANSPORTS IN LATE SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
LC01	63.4	32.8	8	0.0	15.5	0	7.1	0.5	1.95	17	0.74	1.8	76.2
LC03	175.3	71.7	8	48.5	33.7	0	61.9	2.4	9.60	17	0.58	3.3	60.1
LC04	171.7	85.8	8	31.0	40.4	0	37.6	3.2	12.80	17	0.71	4.5	73.5
LC08	112.8	30.5	8	48.8	14.4	0	60.0	2.0	8.10	17	0.39	4.3	39.8
LC09	132.6	60.7	8	25.3	28.5	0	35.4	2.9	11.50	17	0.65	5.2	67.3
LC10	174.4	63.8	8	55.0	30.0	0	72.6	2.9	11.50	17	0.52	4.0	53.8
LC13	175.6	41.3	8	86.4	19.5	0	106.9	2.0	8.20	17	0.34	2.8	34.6
LC14	414.9	82.0	8	267.8	34.9	0	289.9	6.2	24.60	17	0.25	3.6	28.2
LC15	320.6	97.0	8	153.4	45.6	0	170.0	6.9	27.50	17	0.43	5.1	44.5
LC16	222.1	118.6	8	30.4	55.8	0	39.7	2.3	9.30	17	0.76	2.5	78.5
LM01A	375.3	184.1	12	88.0	88.4	0	90.8	6.2	25.00	25	0.71	4.0	72.6
LM01B	799.1	339.2	12	272.9	162.8	0	285.1	8.7	34.70	25	0.62	2.6	62.8
LM03	433.6	198.0	12	109.4	95.0	0	128.6	5.0	19.90	25	0.66	2.8	67.6
LM04	854.4	340.9	12	320.8	163.6	0	337.8	14.4	57.70	25	0.58	4.1	59.0
LM05	550.8	166.9	12	294.0	68.2	0	303.7	12.2	48.90	25	0.38	5.3	42.7
LM06	1528.4	450.0	12	840.8	216.0	0	850.4	31.9	127.50	25	0.43	5.0	43.6
LM07	1126.9	426.7	12	463.5	204.8	0	483.4	14.1	56.50	25	0.55	3.0	56.0
LM08	1107.6	460.8	12	397.4	221.2	0	413.6	19.2	76.90	25	0.61	4.2	61.6
LM09	870.2	288.1	12	421.4	138.3	0	431.9	15.7	62.80	25	0.48	4.3	49.0
LM10	339.6	175.6	12	60.7	84.3	0	67.7	4.8	19.20	25	0.75	3.4	76.5
LM11	830.9	281.4	12	391.2	134.3	0	403.2	21.1	84.40	25	0.49	6.1	50.0
LM12	756.2	247.7	12	362.8	118.9	0	377.6	15.2	60.80	25	0.48	4.8	48.5
LM13	758.5	365.9	12	199.1	175.6	0	205.0	9.4	37.70	25	0.70	3.0	71.4
LM14	1546.7	477.7	12	867.6	177.8	0	879.2	32.0	128.00	25	0.35	5.0	42.4
LM15	761.2	393.2	12	153.1	188.7	0	167.3	9.2	37.00	25	0.75	2.9	76.4
LM16	1144.2	398.8	12	549.1	170.2	0	563.3	26.1	104.20	25	0.45	5.5	49.7
LM17A	994.9	383.2	12	435.4	159.8	0	439.9	26.4	105.80	25	0.49	6.4	54.6
LM17B	2280.6	507.5	12	1539.7	208.4	0	1552.8	38.1	152.20	25	0.28	4.0	31.4
LM18A	258.1	121.9	12	59.9	58.5	0	65.7	4.2	16.90	25	0.69	3.9	69.9
LM18B	1479.8	604.0	12	561.1	289.9	0	573.9	15.9	63.80	25	0.59	2.6	60.4
LM19	1956.9	721.6	12	853.9	346.4	0	876.9	29.1	116.40	25	0.54	3.6	54.6
LM20	2228.9	832.4	12	959.3	399.5	0	985.0	29.0	116.10	25	0.54	3.1	55.3

TABLE 11. SIMULATION OF H8~650 WITH ONE TRANSPORT IN EARLY SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
EC09	108.5	61.0	8	0.0	28.7	2.3	16.6	1.4	5.6	17	0.80	3.1	82.7
EC10	132.9	71.9	8	0.0	33.8	2.3	33.2	1.7	6.6	17	0.77	3.0	79.5
EC11	59.9	30.1	8	0.0	14.2	2.3	12.1	1.2	5.0	17	0.72	5.0	74.0
EC12	58.3	25.1	8	0.0	11.8	2.3	25.1	1.1	4.3	17	0.61	4.5	63.3
EC13	94.7	41.3	8	0.0	19.5	2.3	48.4	1.6	6.5	17	0.62	4.1	64.2
EC14	301.6	99.3	8	112.6	46.7	11.5	232.2	5.2	20.8	17	0.47	4.1	48.4
EC15	189.7	110.5	8	0.0	52.0	2.3	32.6	1.8	7.2	17	0.83	2.3	85.7
EC16	60.5	30.9	8	0.0	14.5	2.3	4.8	0.5	2.1	17	0.73	2.1	75.0
EM01A	303.4	189.8	12	0.0	91.1	6.9	30.3	3.6	14.4	25	0.91	2.8	92.6
EM01B	233.3	135.8	12	0.0	65.2	2.3	41.3	1.5	5.9	25	0.85	1.5	86.2
EM05	508.6	308.0	12	5.4	147.8	29.9	234.9	13.4	53.6	25	0.88	6.3	89.6
EM06	352.5	220.5	12	0.0	105.8	6.9	67.5	3.0	12.1	25	0.91	2.1	92.6
EM07	465.6	282.4	12	0.0	135.5	18.4	217.9	8.4	33.6	25	0.88	4.3	89.8
EM09	458.2	288.1	12	0.0	138.3	11.5	152.6	5.1	20.5	25	0.91	2.7	93.1
EM11	454.2	279.5	12	0.0	134.2	13.8	112.9	6.7	27.0	25	0.90	3.6	91.1
EM12	334.6	204.5	12	0.0	98.2	6.9	66.3	3.1	12.2	25	0.89	2.2	90.5
EM13	611.5	364.8	12	15.0	175.1	39.1	346.7	17.3	69.2	25	0.87	6.8	88.3
EM14	581.2	369.3	12	0.0	177.3	13.8	214.3	6.3	25.1	25	0.92	2.6	94.0
EM15	706.8	391.1	12	44.5	187.6	55.2	448.1	24.8	99.0	25	0.80	8.4	81.9
EM16	629.9	393.2	12	0.0	188.7	20.7	212.4	9.1	36.3	25	0.91	3.5	92.4
EM17	1927.9	826.7	12	584.6	396.8	103.5	1366.7	45.4	181.5	25	0.62	5.6	63.5
EM18	1296.1	826.7	12	9.2	396.8	43.7	660.6	19.8	79.3	25	0.93	3.7	94.4
EM19A	1533.0	443.9	12	768.4	207.5	75.9	1332.0	33.3	133.2	25	0.41	5.2	42.5
EM19B	340.2	208.5	12	0.0	100.1	6.9	58.5	3.5	13.9	25	0.89	2.4	90.7
EM20	1127.0	609.1	12	136.3	292.4	52.9	831.0	23.1	92.4	25	0.78	4.9	80.0

TABLE 12. SIMULATION OF H3-650 WITH ONE TRANSPORT IN LATE SUMMER

SITE	TOTAL	WORK	TURN	WAIT	CLEAN	CHANGE	TRANS	LOADS	MASS	SWATHS	RATE_A	RATE_M	EFFIC_H
LC01	65.7	32.8	8	0.0	15.5	2.3	7.1	0.5	2.0	17	0.71	1.8	73.5
LC03	131.4	71.7	8	0.0	33.7	4.6	51.4	2.4	9.6	17	0.78	4.4	80.2
LC04	147.6	85.8	8	0.0	40.4	6.9	33.6	3.2	12.8	17	0.83	5.2	85.5
LC08	71.6	30.5	8	2.9	14.4	4.6	50.5	2.0	8.1	17	0.61	6.8	62.7
LC09	111.8	60.7	8	0.0	28.5	4.6	31.3	2.9	11.5	17	0.77	6.2	79.8
LC10	124.5	63.8	8	0.5	30.0	4.6	61.8	2.9	11.5	17	0.73	5.6	75.3
LC13	112.0	41.3	8	18.1	19.5	4.6	88.8	2.0	8.2	17	0.53	4.4	54.3
LC14	315.7	82.0	8	154.9	34.9	13.8	269.7	6.2	24.6	17	0.34	4.7	37.0
LC15	245.4	97.0	8	64.3	45.6	13.8	160.1	6.9	27.5	17	0.56	6.7	58.1
LC16	196.3	118.6	8	0.0	55.8	4.6	34.0	2.3	9.3	17	0.86	2.9	88.8
LM01A	301.1	184.1	12	0.0	88.4	13.8	85.5	6.3	25.0	25	0.89	5.0	90.5
LM01B	564.3	339.2	12	19.7	162.8	18.4	269.5	8.7	34.7	25	0.87	3.7	89.6
LM03	333.4	198.0	12	0.0	95.0	9.2	115.1	5.0	19.9	25	0.86	3.6	87.9
LM04	589.4	340.9	12	23.6	163.6	32.2	332.8	14.4	57.7	25	0.84	5.9	85.6
LM05	372.1	166.9	12	87.7	68.2	27.6	294.6	12.2	48.9	25	0.56	7.9	63.2
LM06	1076.8	450.0	12	317.9	216.0	71.3	843.4	31.9	127.5	25	0.61	7.1	61.8
LM07	774.7	426.7	12	79.1	204.8	32.2	466.9	14.1	56.5	25	0.80	4.4	81.5
LM08	765.4	460.8	12	11.5	221.2	43.7	409.5	19.2	76.9	25	0.88	6.0	89.1
LM09	578.0	288.0	12	94.8	138.3	34.5	421.5	15.7	62.8	25	0.72	6.5	73.8
LM10	288.0	175.6	12	0.0	84.3	9.2	63.3	4.8	19.2	25	0.89	4.0	90.2
LM11	535.7	281.4	12	47.8	134.3	48.3	394.1	21.1	84.4	25	0.76	9.5	77.6
LM12	501.1	247.7	12	73.3	118.9	34.5	370.8	15.2	60.8	25	0.72	7.3	73.2
LM13	582.4	365.9	12	2.3	175.6	20.7	193.6	9.4	37.7	25	0.91	3.9	93.0
LM14	1077.8	477.7	12	327.4	177.8	71.3	869.5	32.0	128.0	25	0.50	7.1	60.8
LM15	628.8	393.2	12	0.0	188.7	20.7	156.8	9.2	37.0	25	0.91	3.5	92.5
LM16	783.3	398.8	12	128.4	170.2	59.8	552.3	26.1	104.2	25	0.66	8.0	72.6
LM17A	677.6	383.2	12	58.3	159.8	59.8	437.1	26.4	105.8	25	0.71	9.4	80.1
LM17B	1745.6	507.5	12	917.3	208.4	87.4	1537.7	38.1	152.2	25	0.36	5.2	41.0
LM18	228.7	121.9	12	21.3	58.5	9.2	61.7	4.2	16.9	25	0.78	4.4	78.9
LM18B	986.4	604.0	12	33.2	289.9	34.5	557.2	15.9	63.8	25	0.89	3.9	90.6
LM19	1336.2	721.6	12	166.5	346.4	66.7	858.1	29.1	116.4	25	0.79	5.2	79.9
LM20	1556.2	832.4	12	219.9	399.5	66.7	963.6	29.0	116.1	25	0.78	4.5	79.2

Table 13

Summary of Simulated Production Rates and Efficiency, by Period

Harvester	Number of Transports	Areal Rate acres/hr	Mass Rate tons/hr	Effective Use of Harvester % of time
		Early Summer		
H-400	0	0.38	2.21	57.6
	1	0.51	2.84	77.6
H8-650	0	0.57	3.33	57.9
	1	0.77	4.51	78.3
		Late Summer		
H-400	0	0.34	2.70	52.5
	1	0.47	3.76	73.2
H*-650	0	0.51	4.03	53.1
	1	0.72	5.65	74.4

Table 14

Hypothetical Cost Estimates for Early Summer Harvesting

	System Costs, dollars*			
	H-400		H8-650	
	Number of Transports		Number of Transports	
Site	0	1	0	1
EC09	239.87	471.0	216.88**	379.75
EC10	320.27	588.9	289.48**	465.15
EC11	125.20	259.5	123.20**	209.65
EC12	136.53**	245.4	145.02	204.05
EC13	277.33	441.0	248.60**	331.45
EC14	810.67	1,338.0	745.43**	1,055.60
EC15	424.80	819.6	391.42**	663.95
EC16	112.13	259.2	106.70**	211.75
EM01A	663.33	1,390.8	602.07**	1,061.90
EM01B	556.67	1,043.1	497.57**	816.55
EM05	1,498.53	2,330.4	1,301.85**	1,780.10
EM06	835.60	1,611.6	764.87**	1,233.75
EM07	1,328.53	2,071.5	1,213.30**	1,629.60
EM09	1,175.73	2,096.4	1,106.42**	1,603.70
EM11	1,107.33	2,022.9	999.90**	1,589.70
EM12	777.73	1,488.9	710.60**	1,171.10
EM13	1,864.80	2,814.0	1,663.20**	2,140.25
EM14	1,514.00	2,659.5	1,446.32**	2,034.20
EM15	2,121.33	3,251.7	1,923.72**	2,473.80
EM16	1,608.00	2,814.0	1,498.57**	2,204.65
EM17	5,377.87	9,046.8	4,791.78**	6,747.65
EM18	3,910.27	5,921.1	3,493.23**	4,536.35
EM19A	4,104.80	7,158.9	3,694.53**	5,365.50
EM19B	762.00	1,511.1	705.28**	1,190.70
EM20	3,515.87	5,145.3	3,237.48**	3,944.50
TOTALS	35,200	58,800	31,900**	45,000

* Assumes the following hourly rates: H-400 = $80/hr, T-650 = $100/hr, H8-650 = $110/hr.

** Most cost-effective.

FILM

1-8